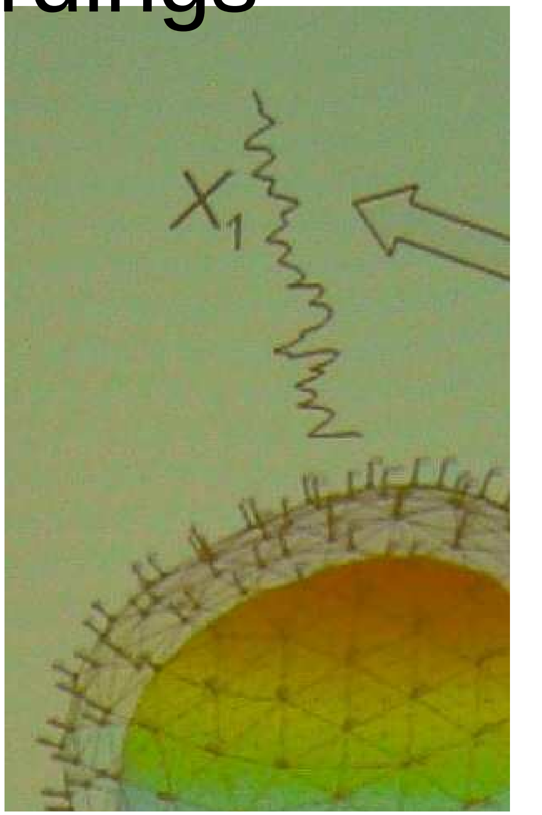
The Hospital for Sick Children

Synchronization in Brain Recordings



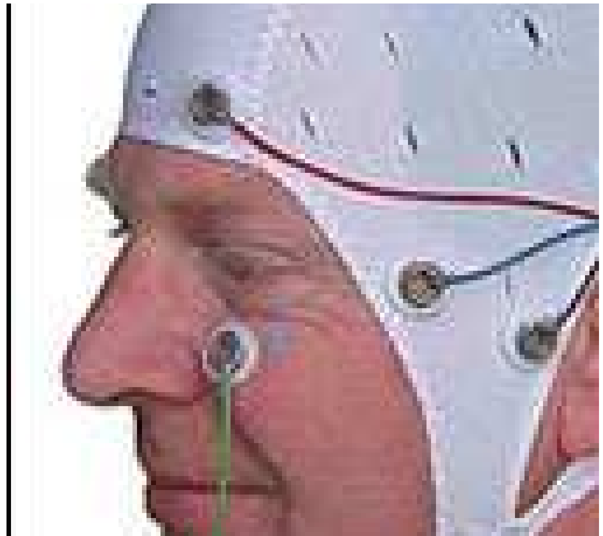
Busy People

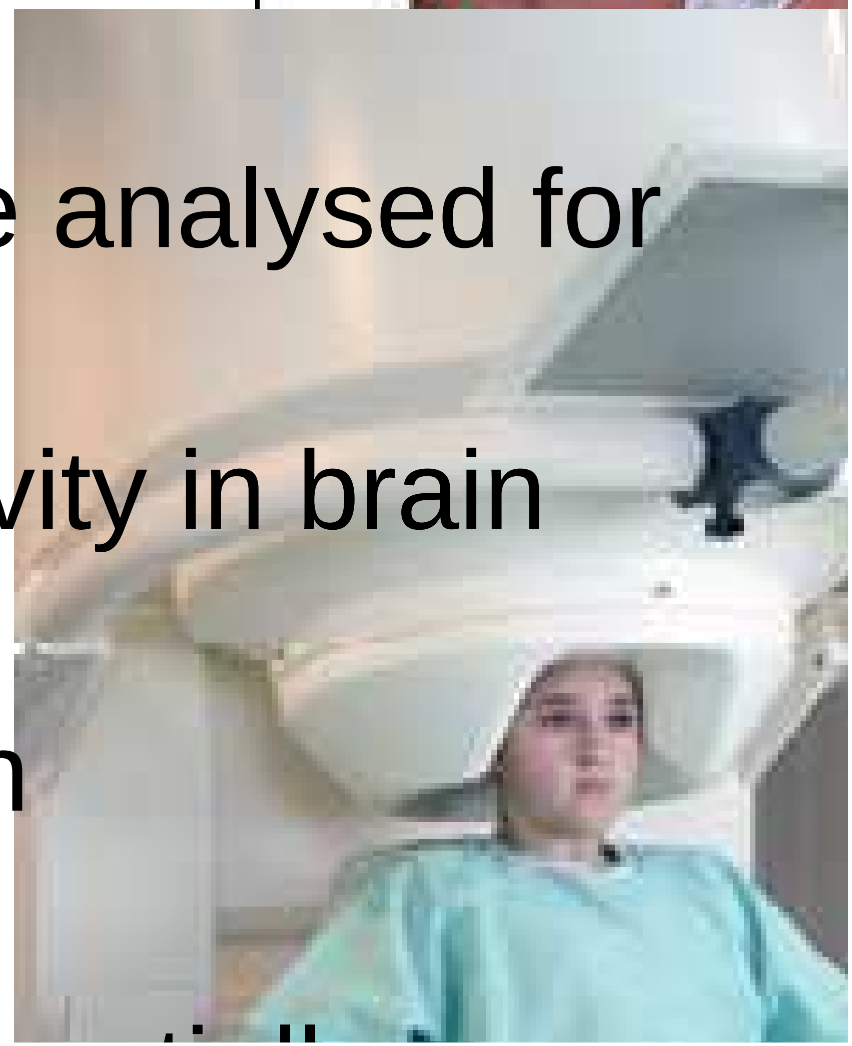
Rajaa Altalli, Maurino Bautista,
David De la Rosa, Irma Diaz Bobadilla, Pe
Howell, Mark McGuinness, Mario Morfir
Ramirez, Alexandra Ortan, Joel Phillips, D
Ross, Vincent Quenneville-Belair, Luz
Angelica Caudillo-Mata,
Jonathan Wylie, Bob Anderssen

and our Industrial Reps

uis Garcia Dominguez, Ramon Guevara E
Jose Luis Velazquez

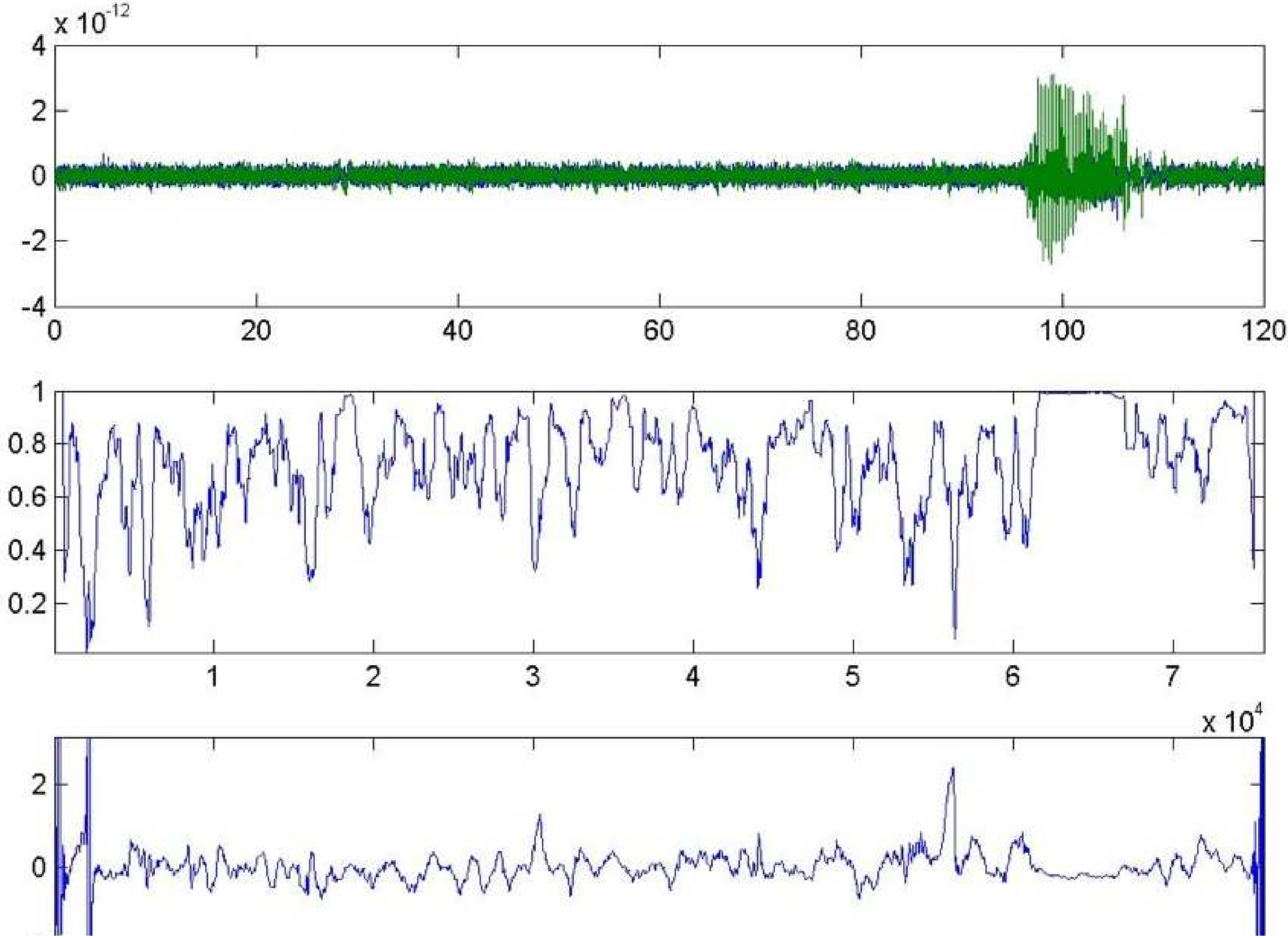
he Problem

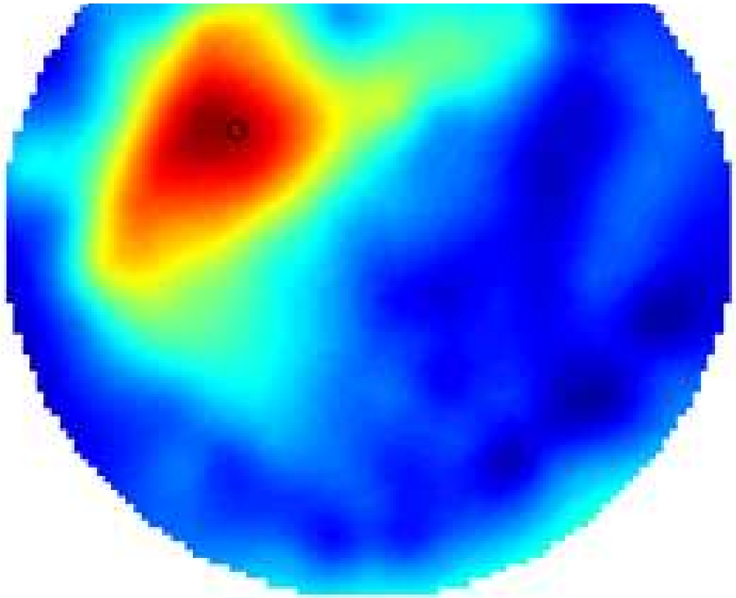
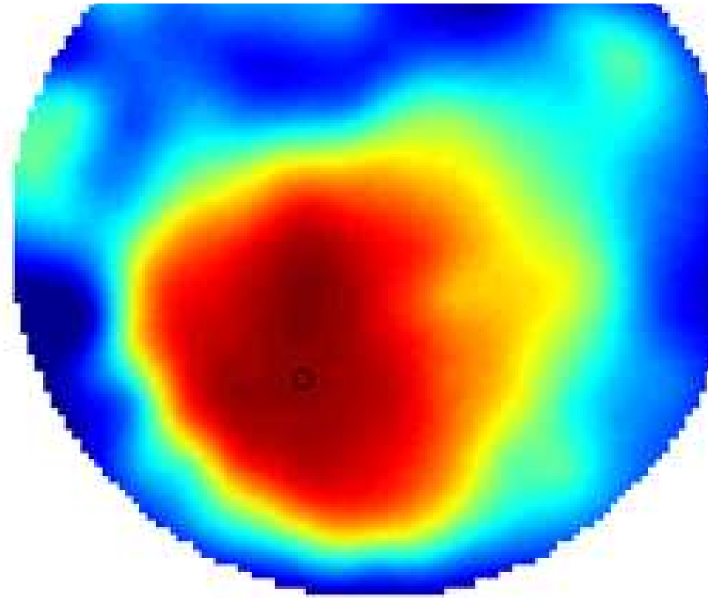




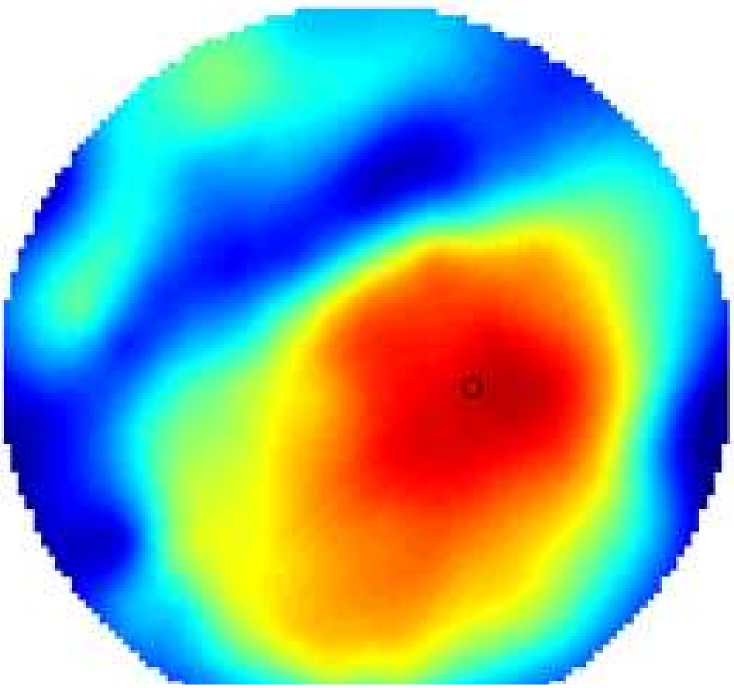
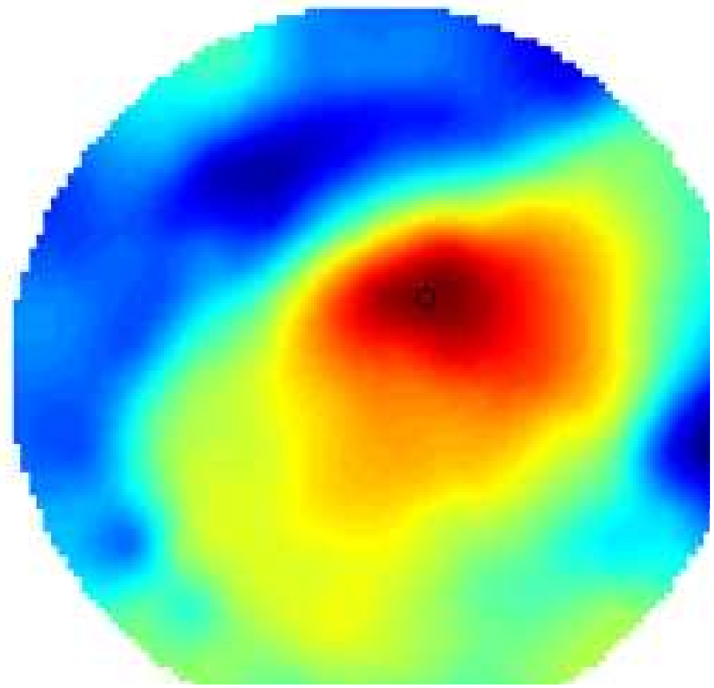
- gnetoencephalogram (MEG)
- ordings are taken at over 100 ations around a head
- e time series data $f_j(t)$ are analysed for chronicity
- study functional connectivity in brain vity
- nt to distinguish between ue synchronicity, and

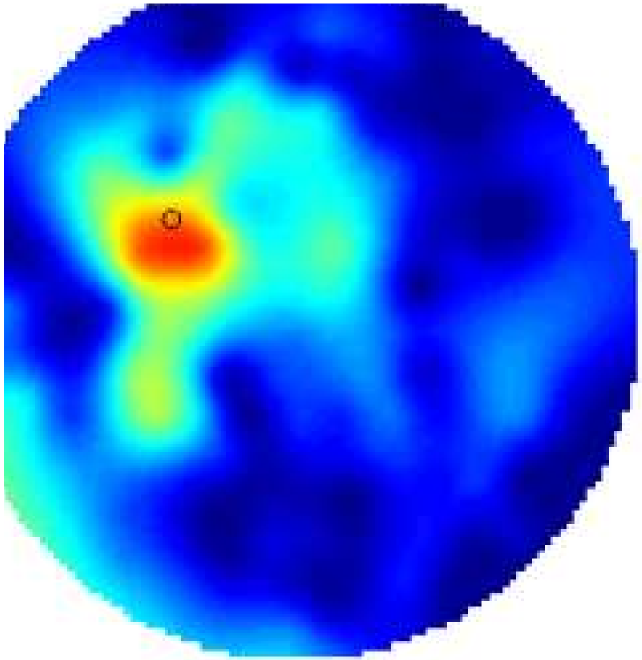
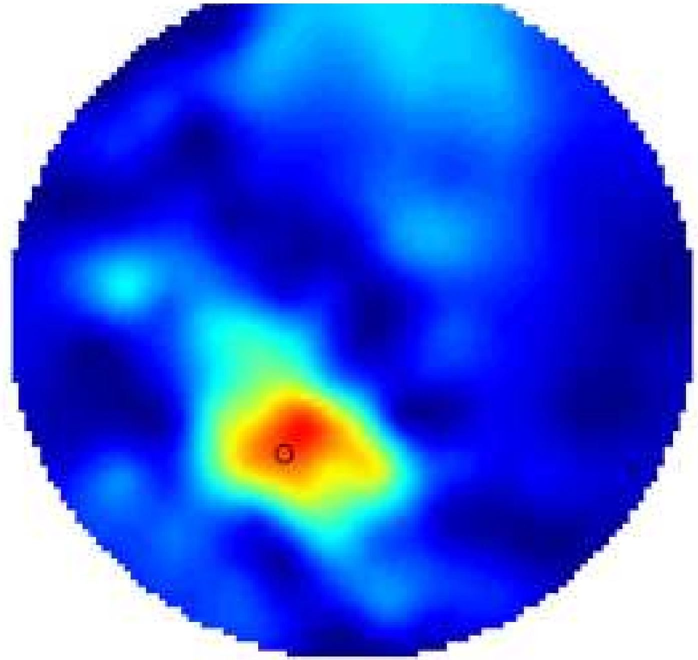
Time series



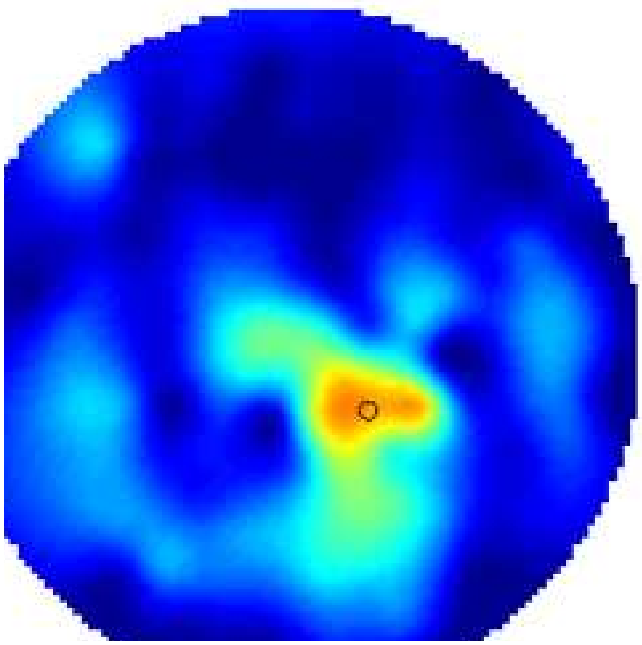
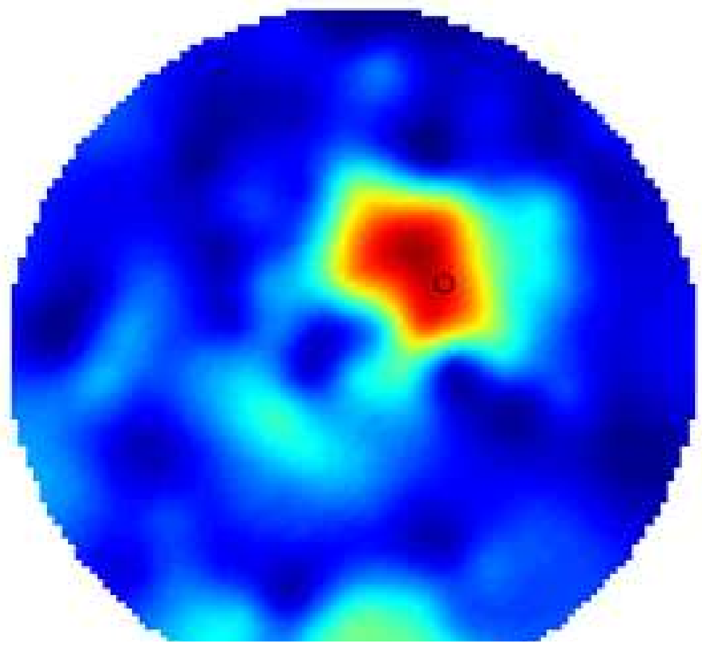



synchronization plot during a seizure

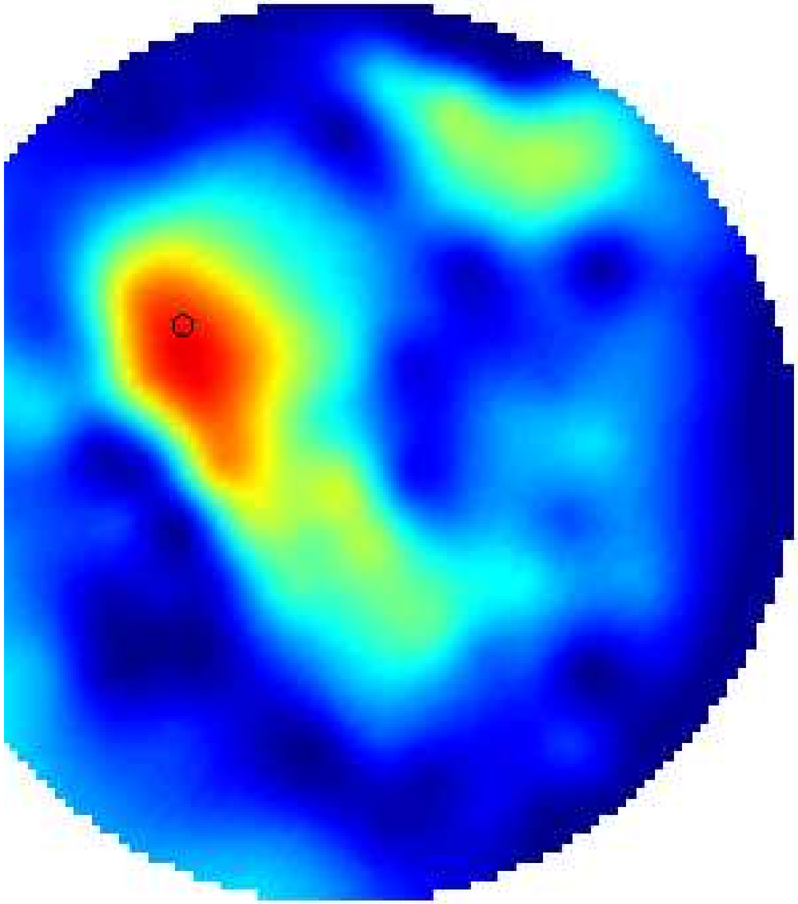



nchronization plot during normal brain act

alse) synchronization is seen if sensors ar
close together, too



how close is too close

Physics

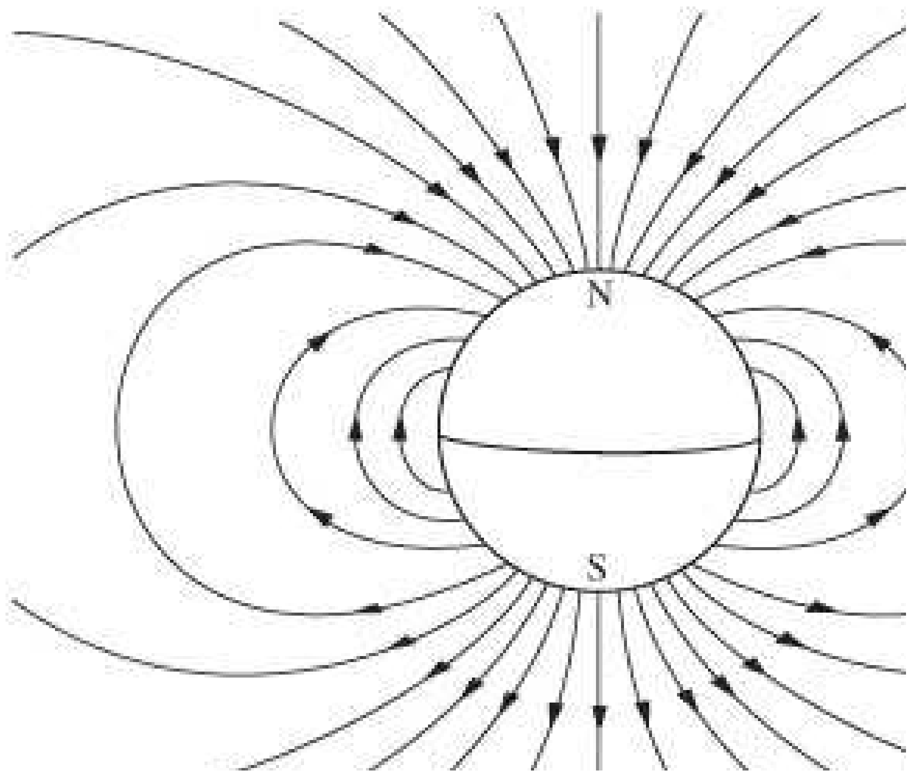
Biot-Savart law:

tic field B due to magnetic dipole:

$$\frac{\mu_0 q(t)}{4\pi r^3}\left[\frac{3(\mathbf{m}\cdot\mathbf{r})\,\mathbf{r}}{r^2}-\mathbf{m}\right]$$

e the dipole is $q(t)\mathbf{m}$

$\mathbf{m}$ is a unit vector



nchronicity

Principle, we could:

Assume n dipoles, each with position x_i, orientation θ_i, time series $F_i(t)$

Use the data at the surface to solve the nverse problem and estimate each of the ime series $F_i(t)$

Then test each pair of time series for synchronicity

Problem.

Too many parameters and not enough data

Unknown number of dipoles

Inverse problem is infeasible

But can we devise a measure that will indicate synchronicity?

Synchronicity

ave a time series $f_j(t)$

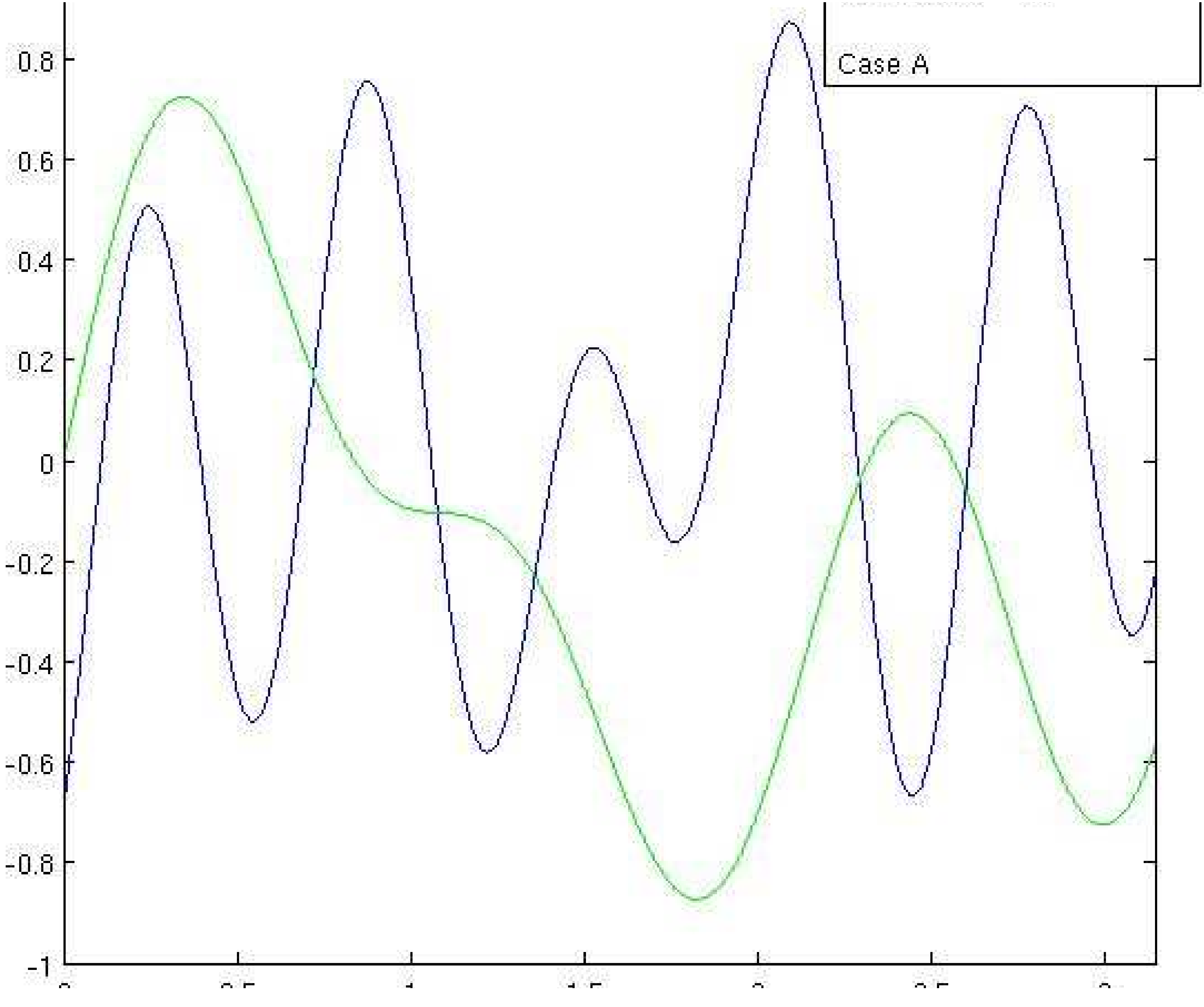
omplexify f_j by using the Hilbert transform

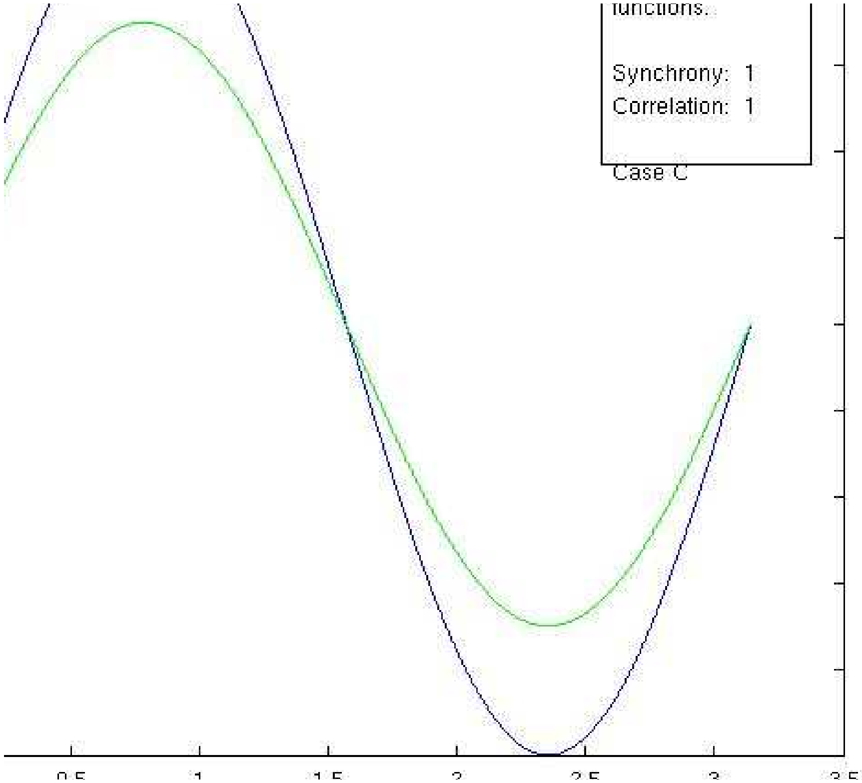
$$\hat{f}(t) = \frac{1}{\pi} P \int_{-\infty}^{\infty} \frac{f(\tau)}{t-\tau} d\tau,$$

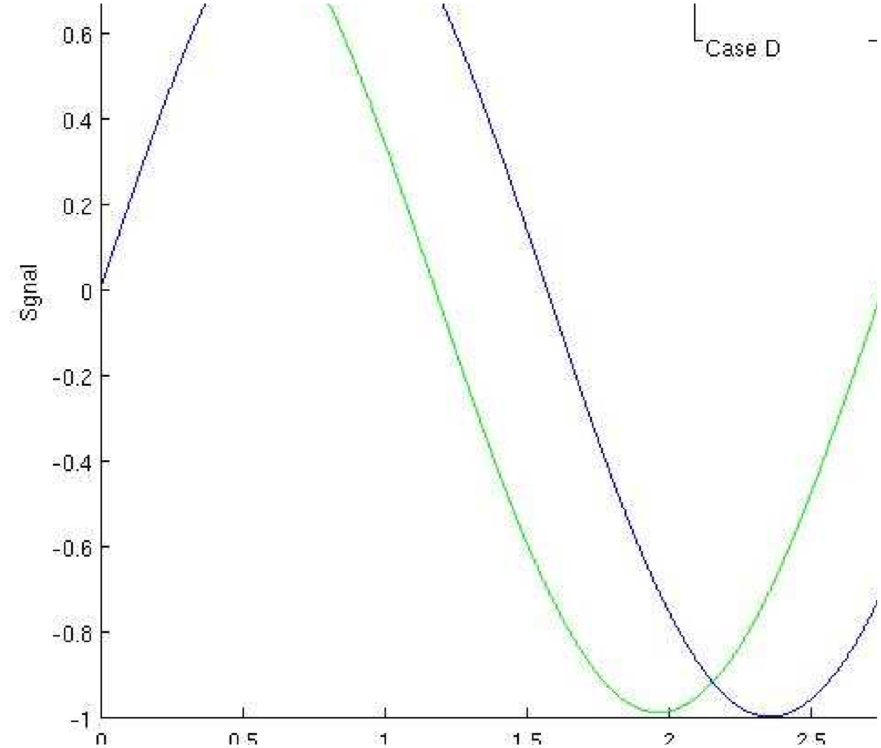
en use $f_j + i\hat{f}_j = re^{i\phi_j}$

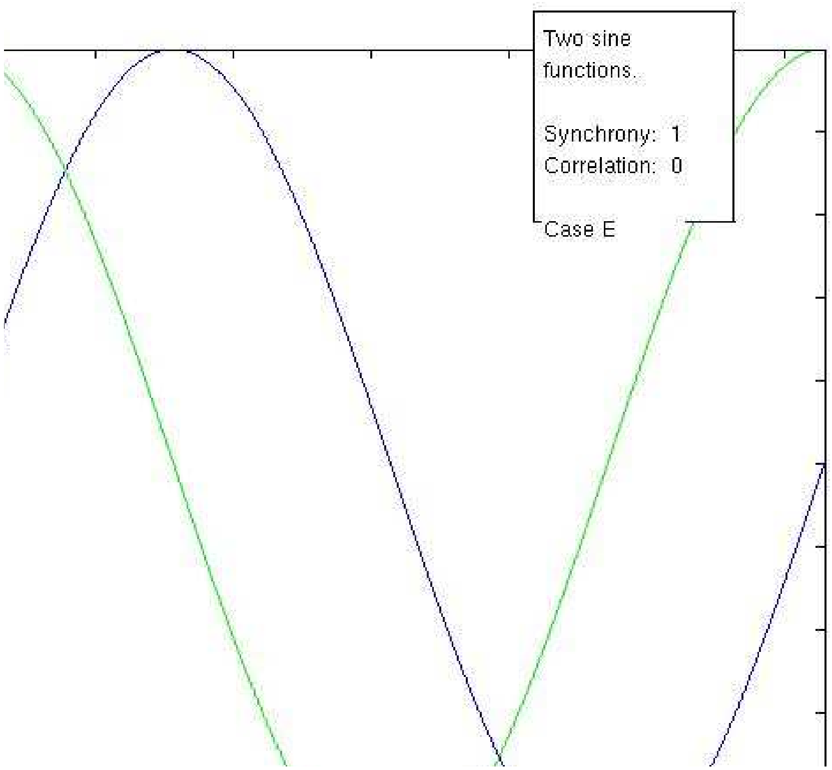
define the phase ϕ_j of the jth sensor

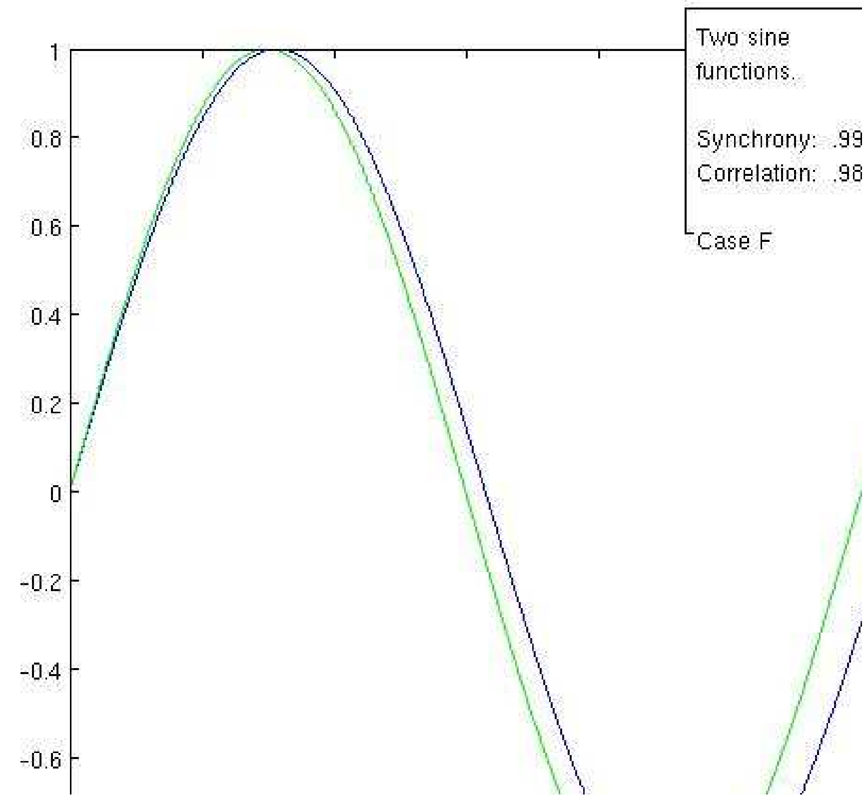
hen form the average $\left| \left\langle e^{i(\phi_j - \phi_k)} \right\rangle \right|$

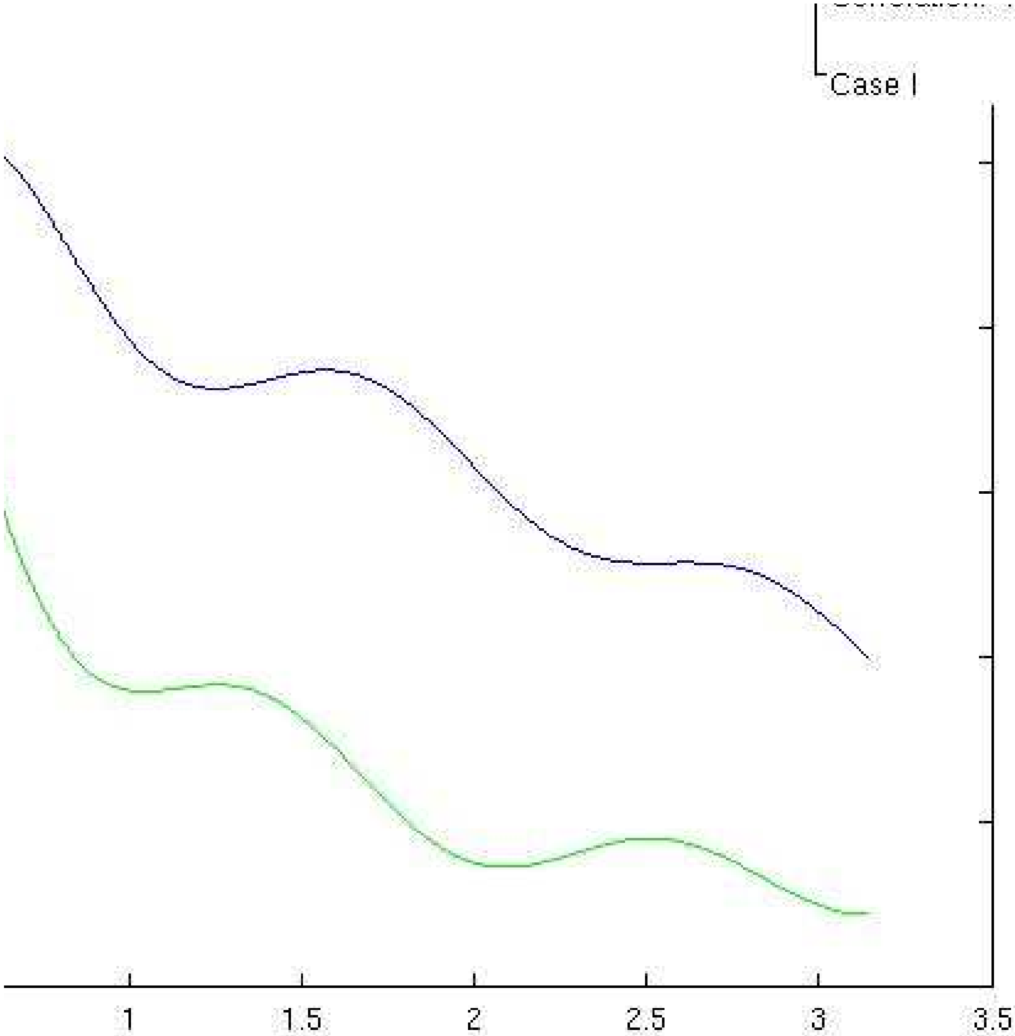

Case A
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1

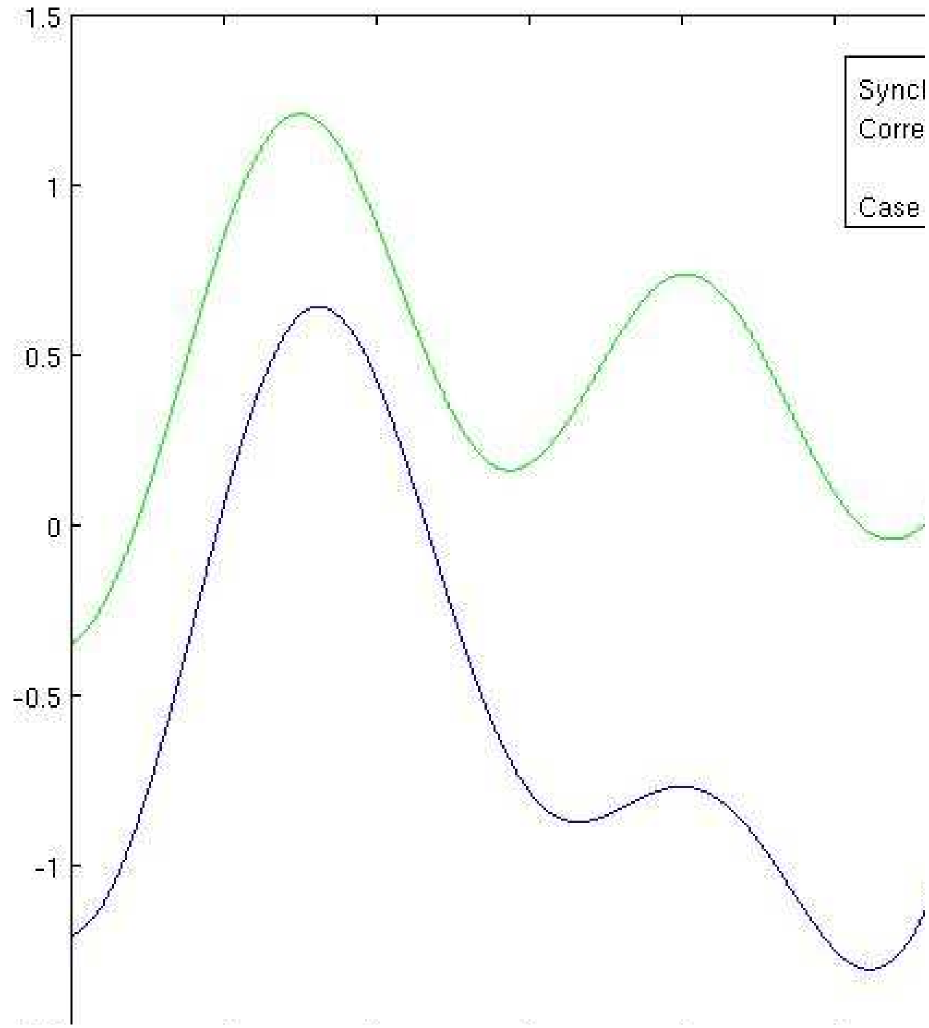

functions.
Synchrony: 1
Correlation: 1
Case C

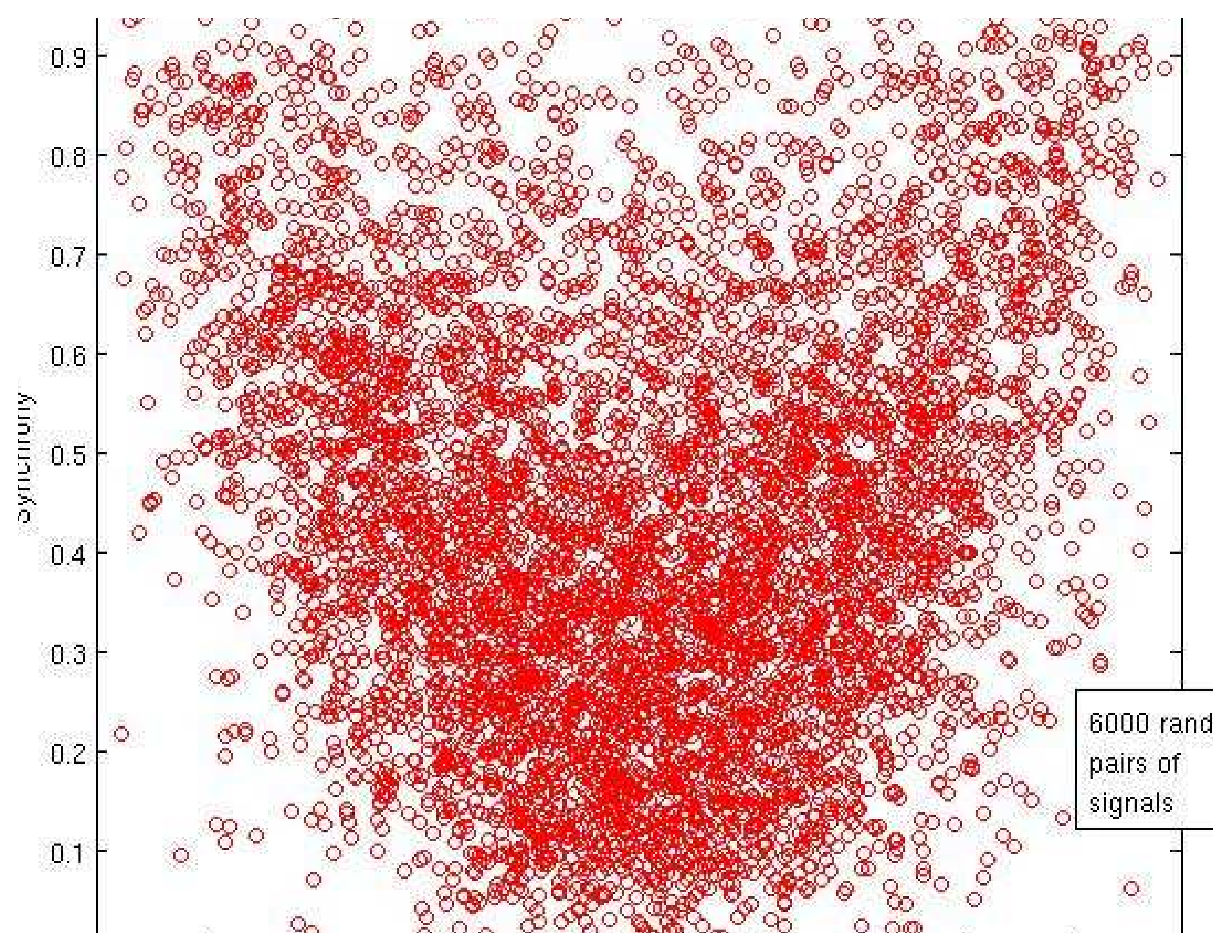

Case D
Sgnal
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1

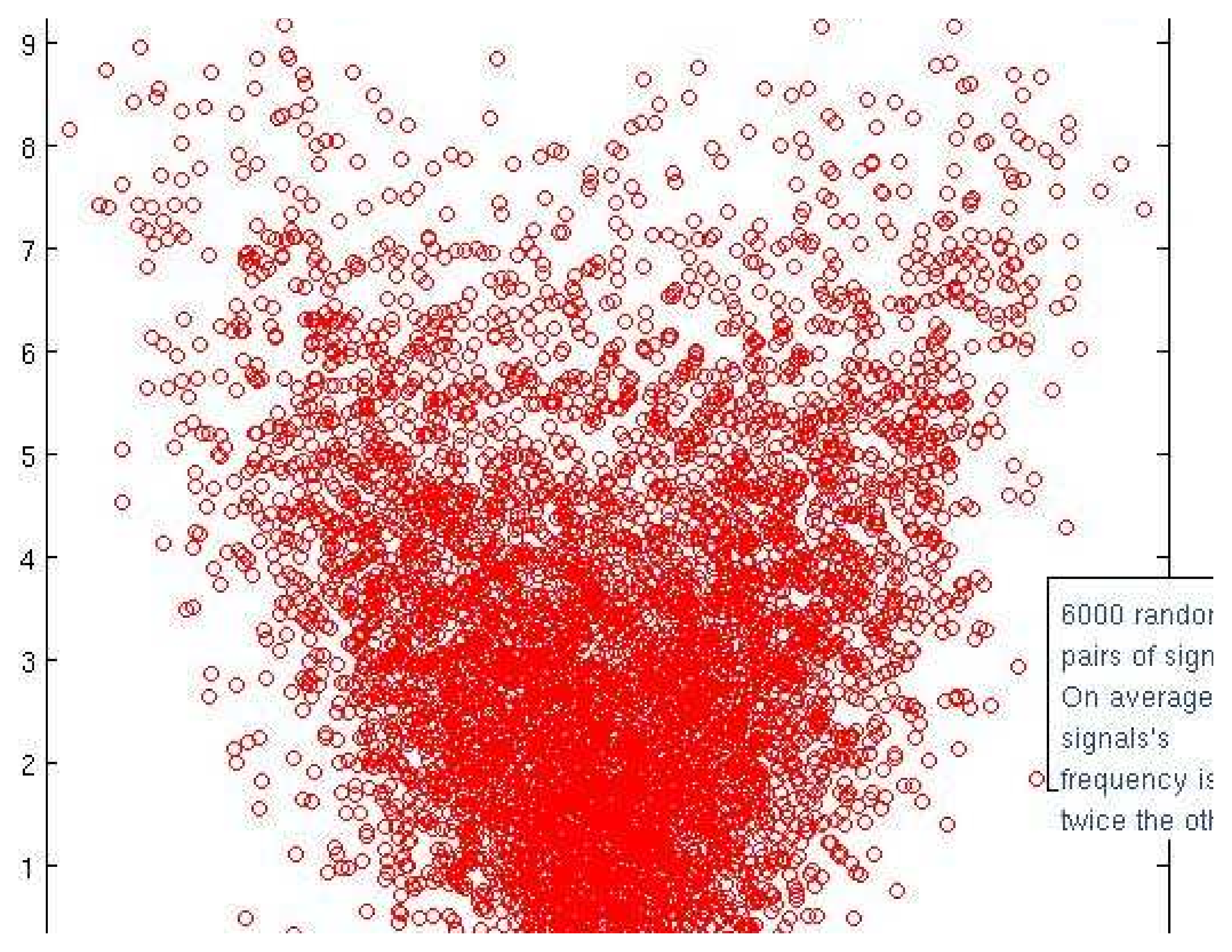

Two sine
functions.
Synchrony: 1
Correlation: 0
Case E


Two sine
functions.
Synchrony: .99
Correlation: .98
Case F
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6


Case I
1
1.5
2
2.5
3
3.5


1.5
1
0.5
0
-0.5
-1
Syncl
Corre
Case


0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
6000 rand
pairs of
signals

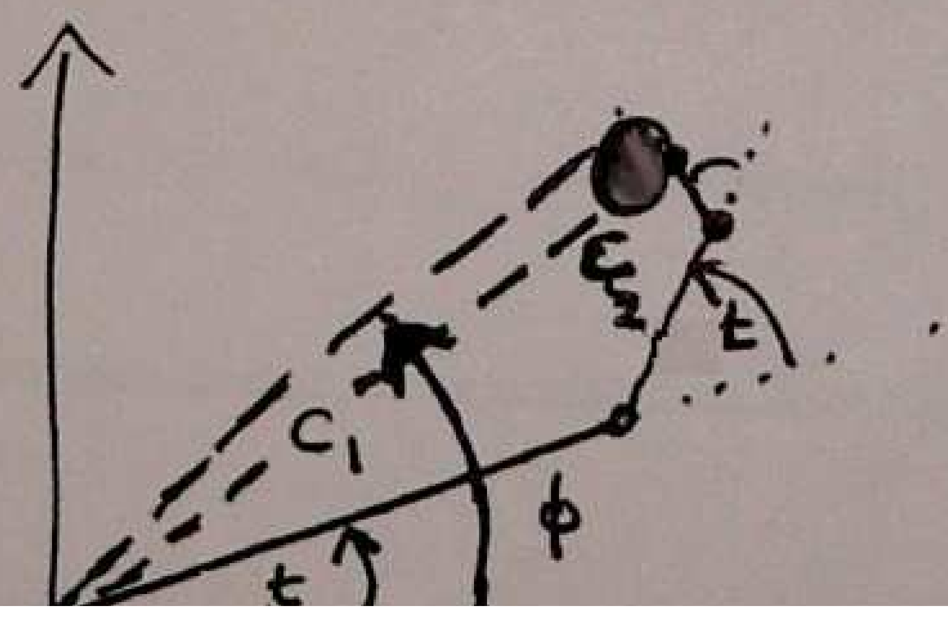

9
8
7
6
5
4
3
2
1
6000 rando
pairs of sign
On average
signals's
frequency is
twice the oth

Effect of filtering?

- a filter is applied to data before calculating phase
- no filter means no synchronization S seen
- white noise gives S ~ 0.3 after filtering

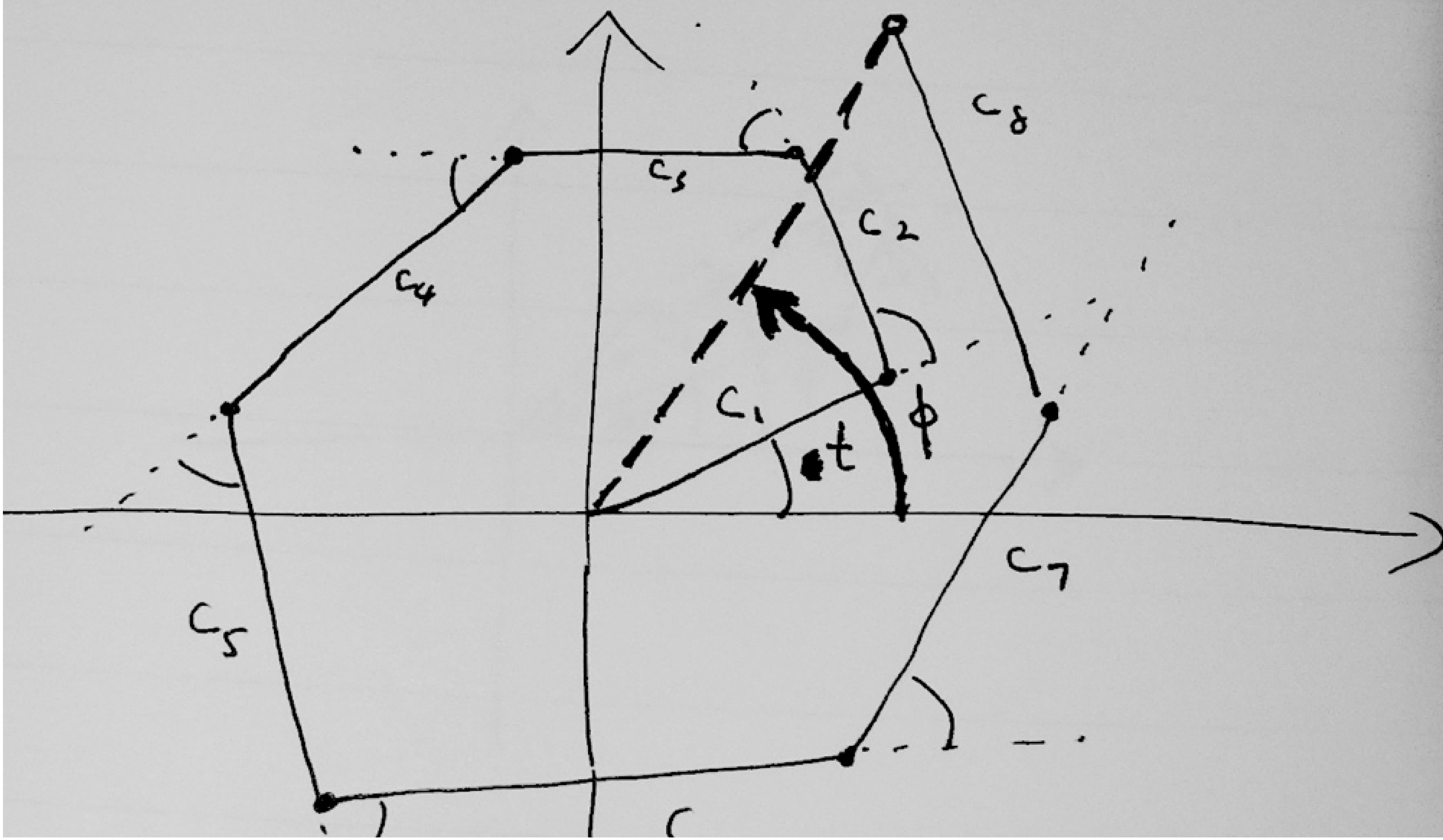
$$F(t) = \sum c_n e^{int}$$

the phase of this is ϕ where



However, for white noise, the c_n's do not decay to zero, and you'll get

wild behaviour for phase



Principal Components Analysis:

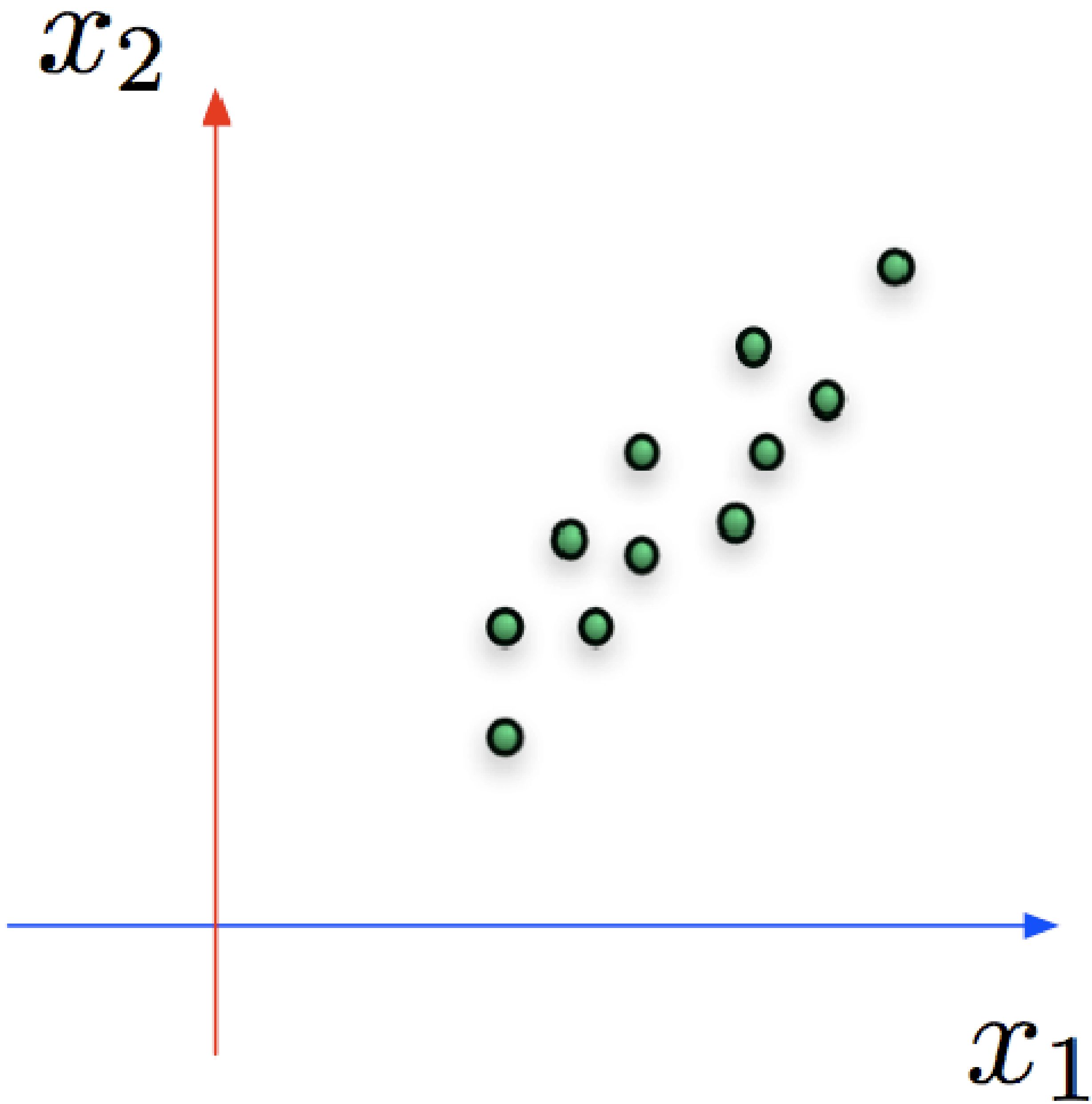
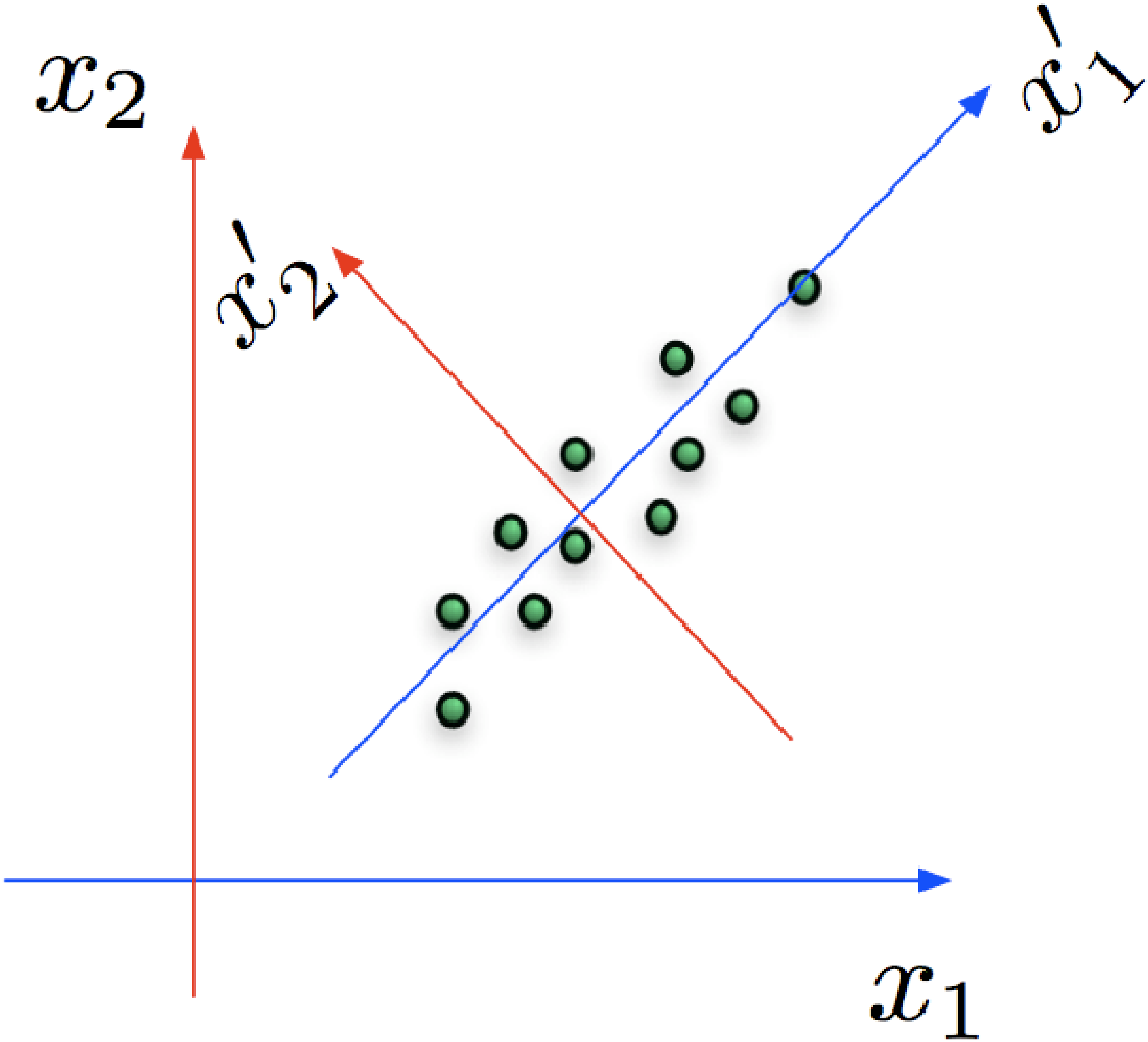
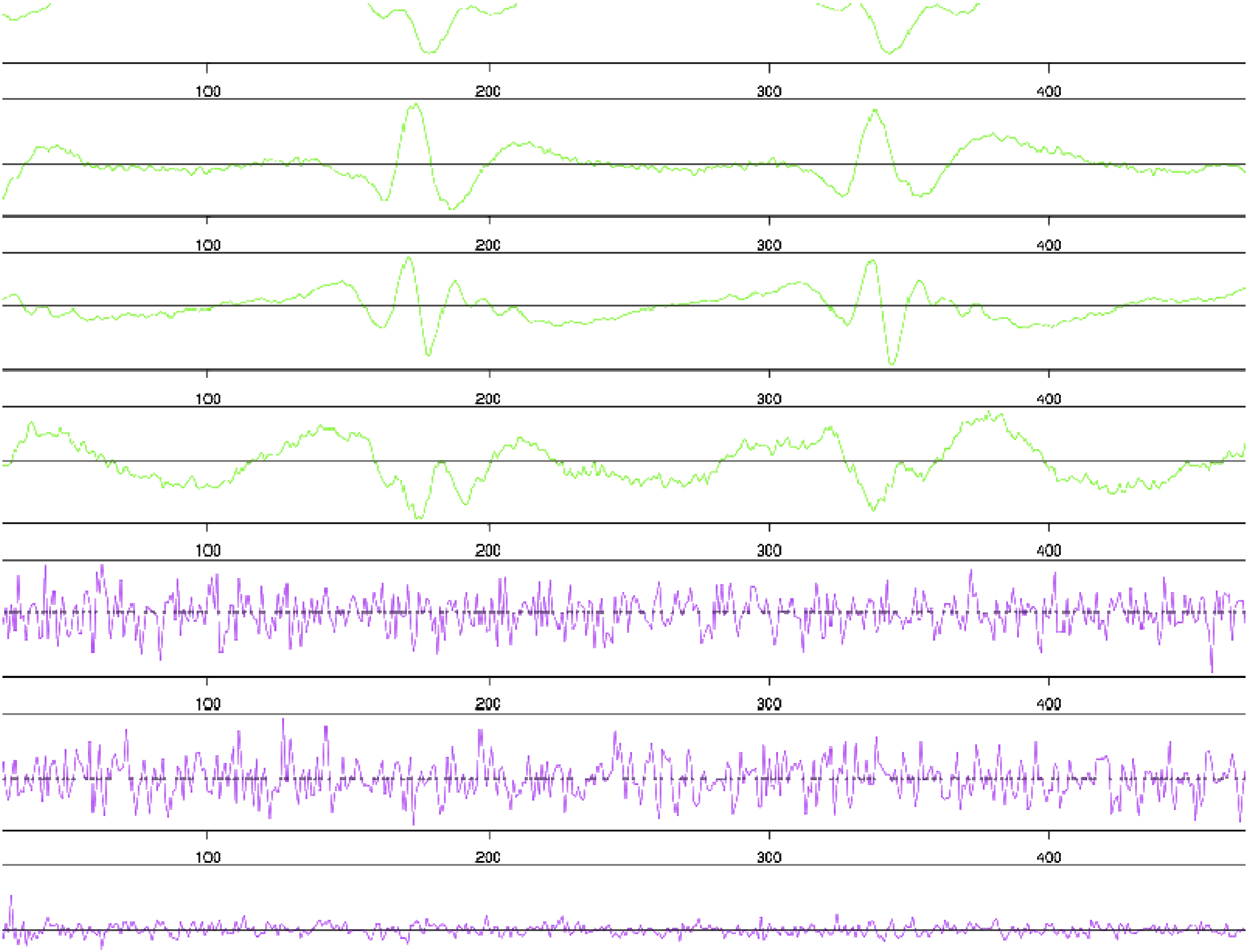
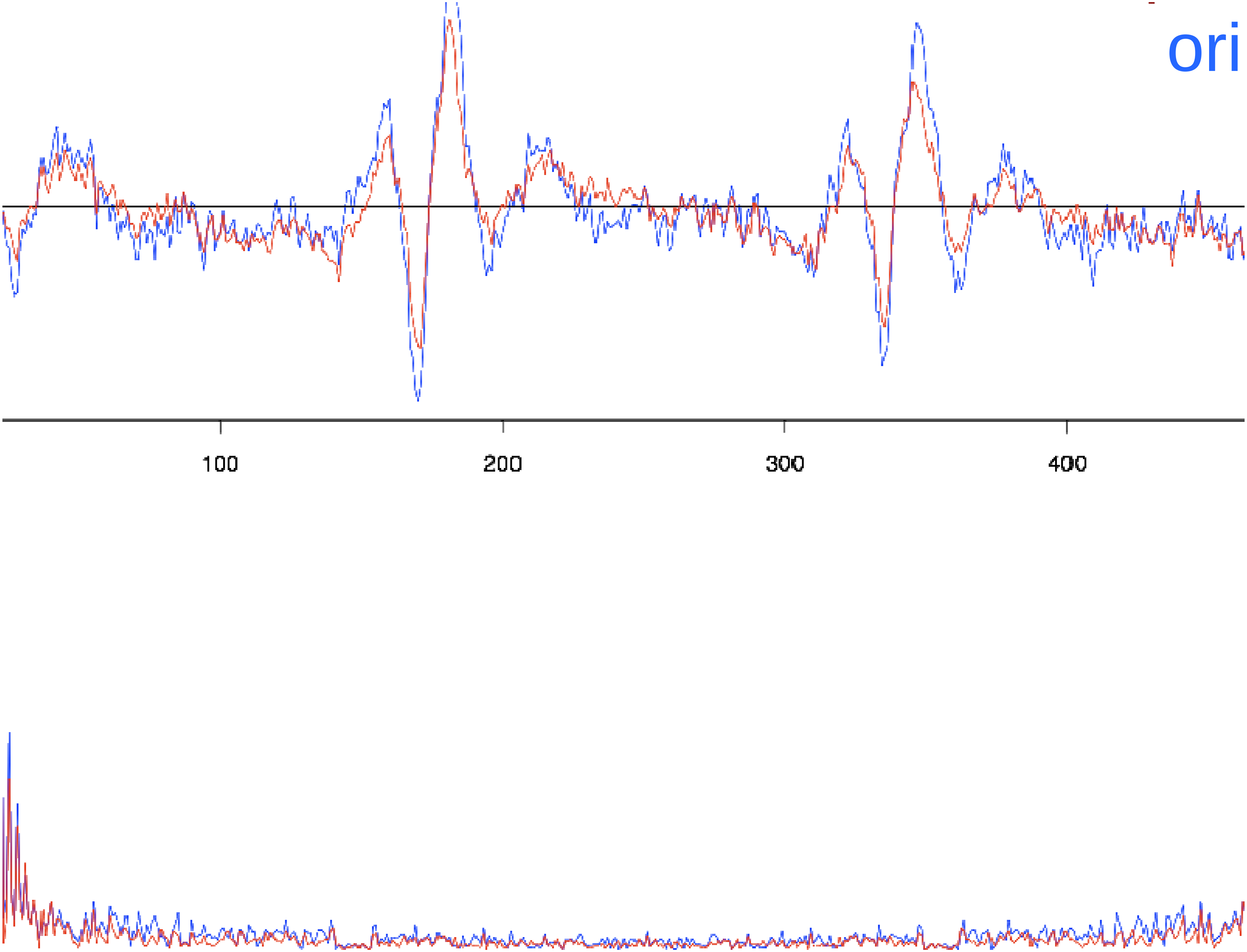


Figure 1: Original Data

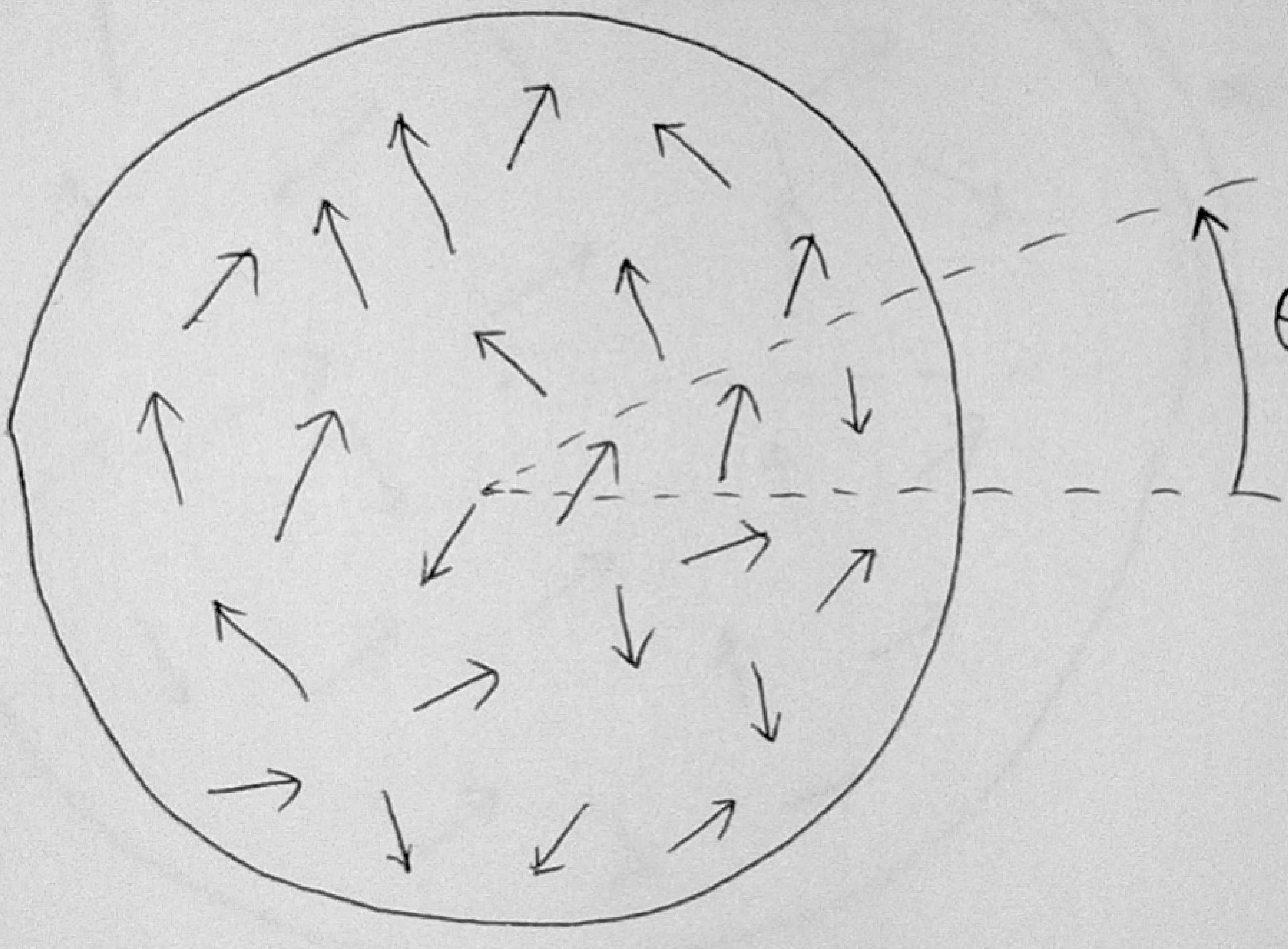


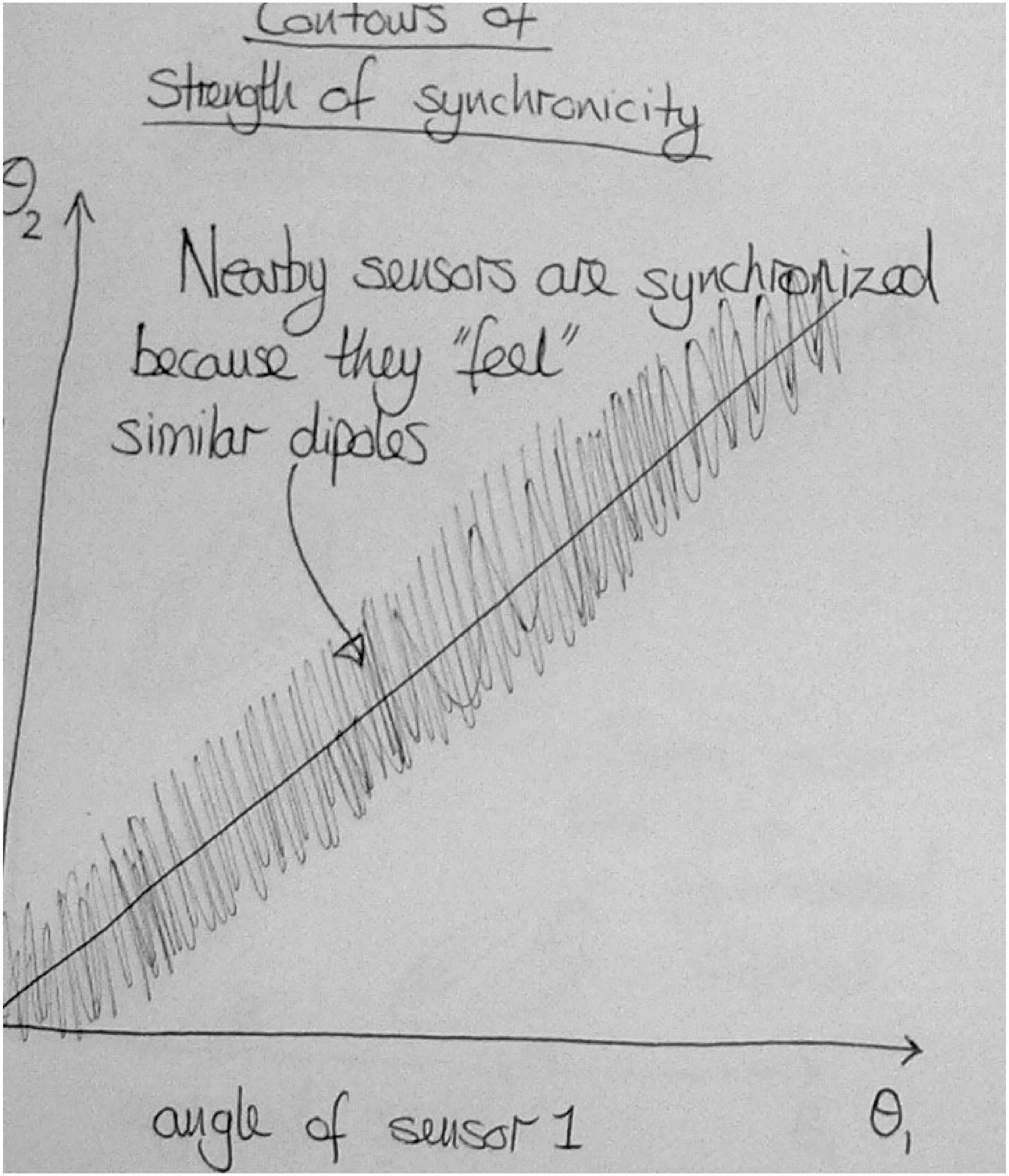
x_2
$x_1^{'}$
$x_2^{'}$
x_1


100 200 300 400
100 200 300 400
100 200 300 400
100 200 300 400
100 200 300 400
100 200 300 400

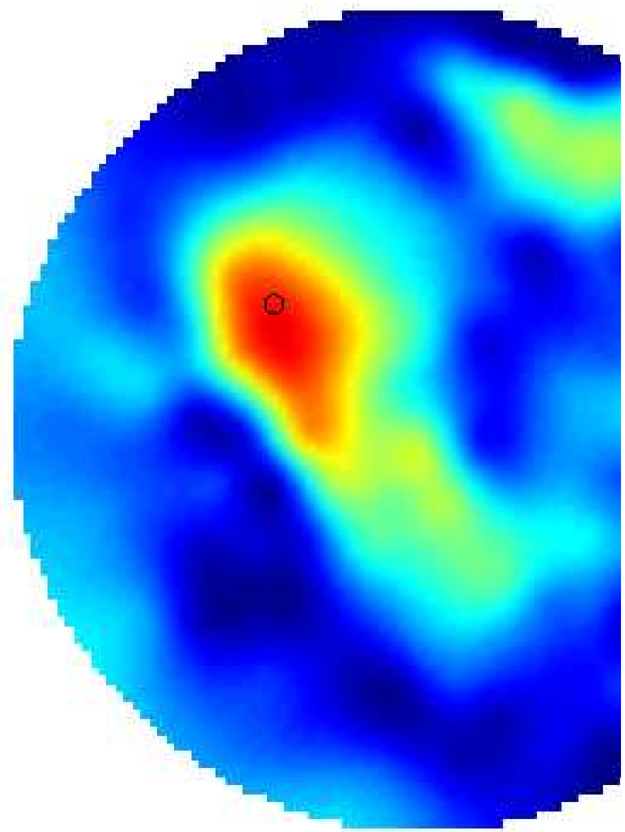

ori
100
200
300
400

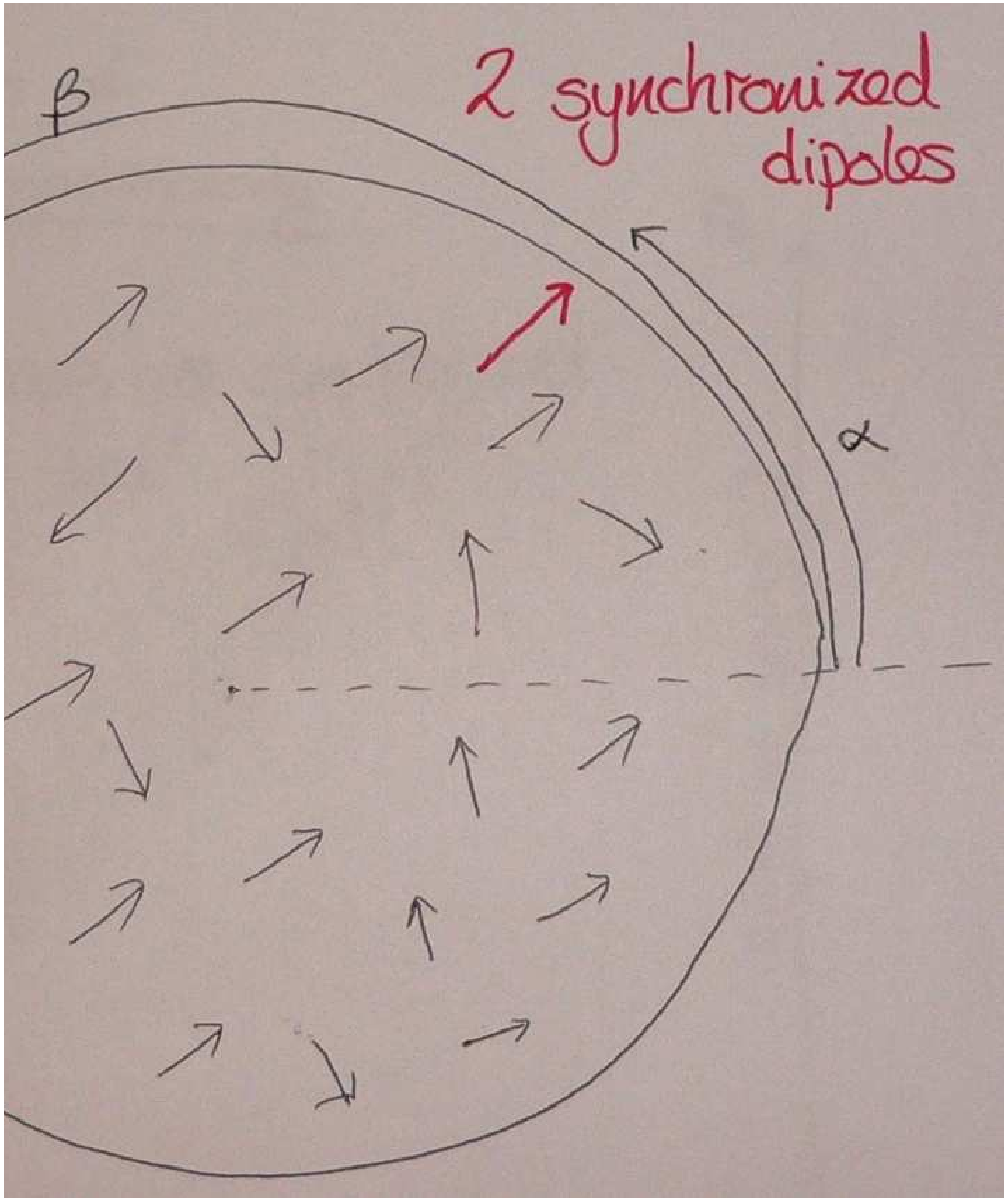
two-dimensional brain!

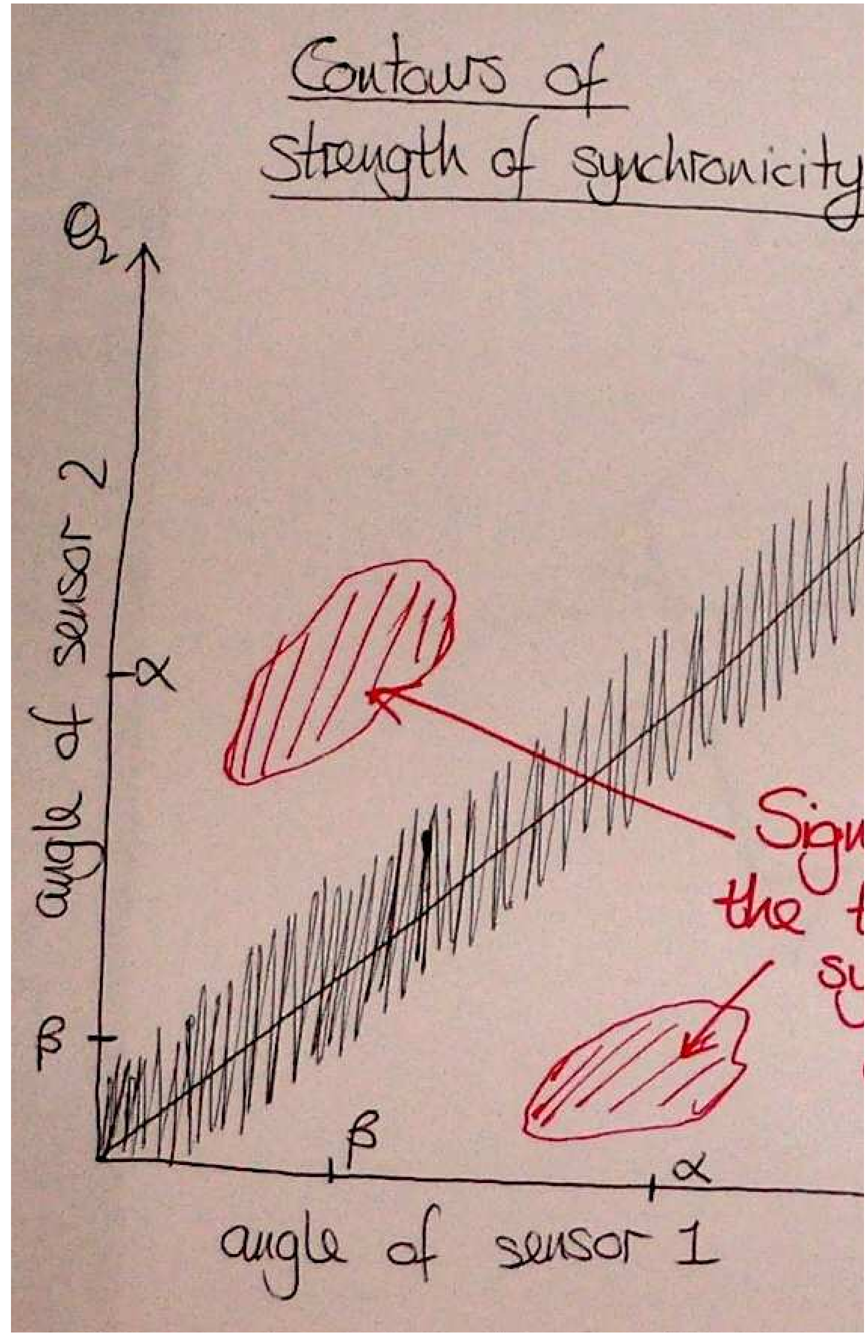




autosynchro




2 synchronized dipoles
β
α

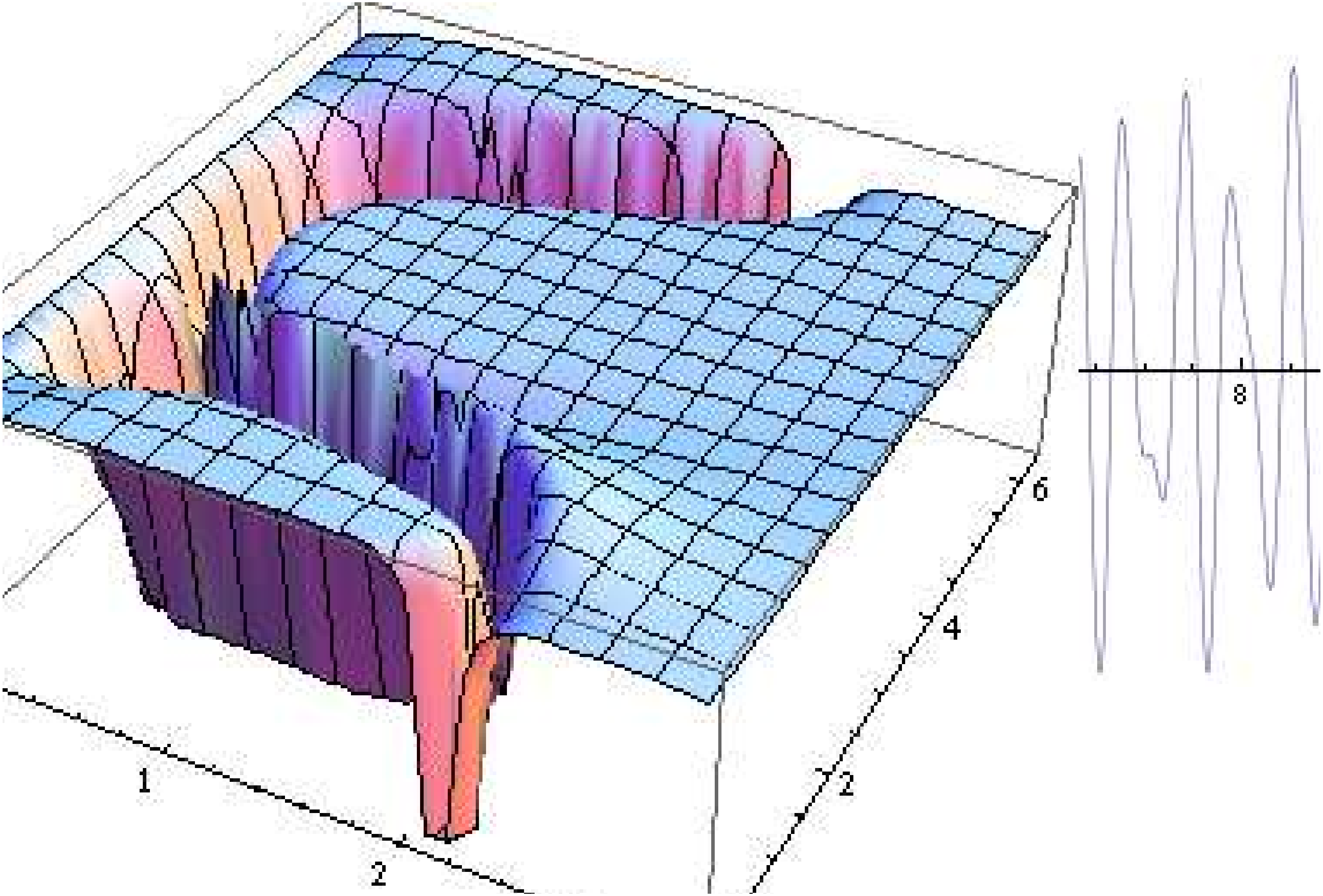

Contours of
strength of synchronicity
θ_2
angle of sensor 2
α
β
β
α
angle of sensor 1
Sig
the
sy

Test Hypotheses

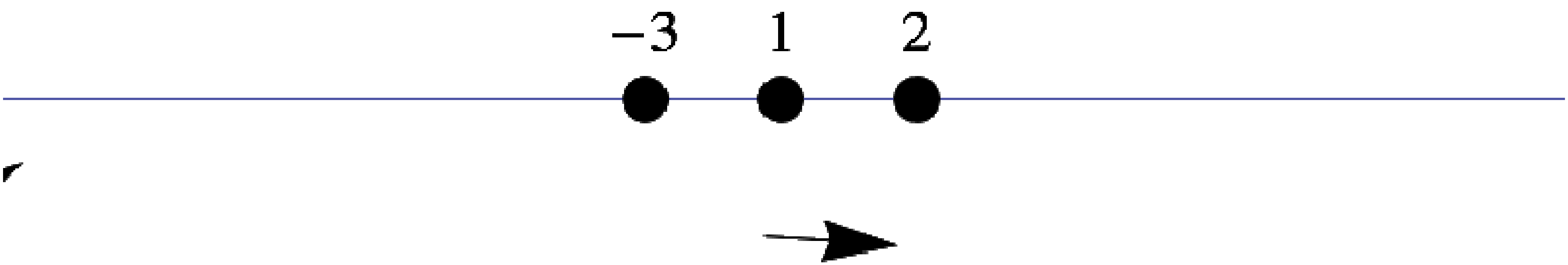
MODEL 1: The data is well described by the unsynchronized brain

MODEL 2: The map produced by a pair of perfectly synchronized dipoles PLUS the map for the unsynchronized brain describes the data

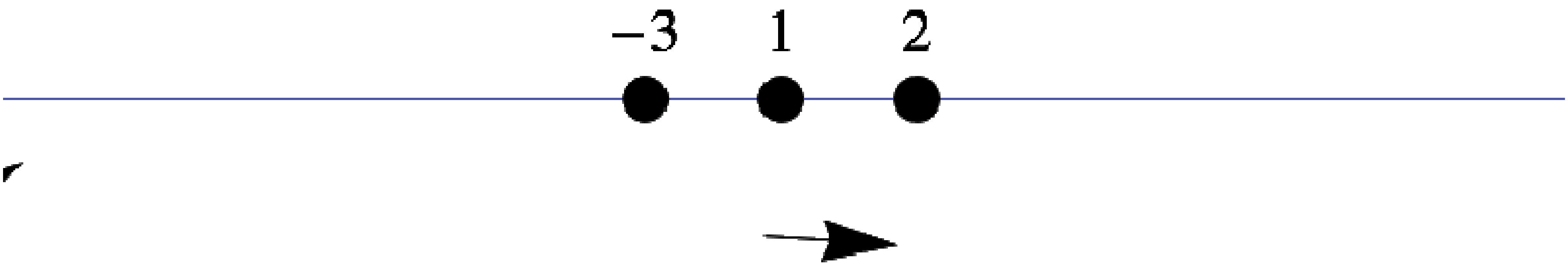
Simulations



ocal inverse problem



$$\mathbf{B} = \frac{\mu_0 q}{4\pi r^3}\left(\frac{3(\mathbf{m}\cdot\mathbf{r})\mathbf{r}}{r^2} - \mathbf{m}\right)$$

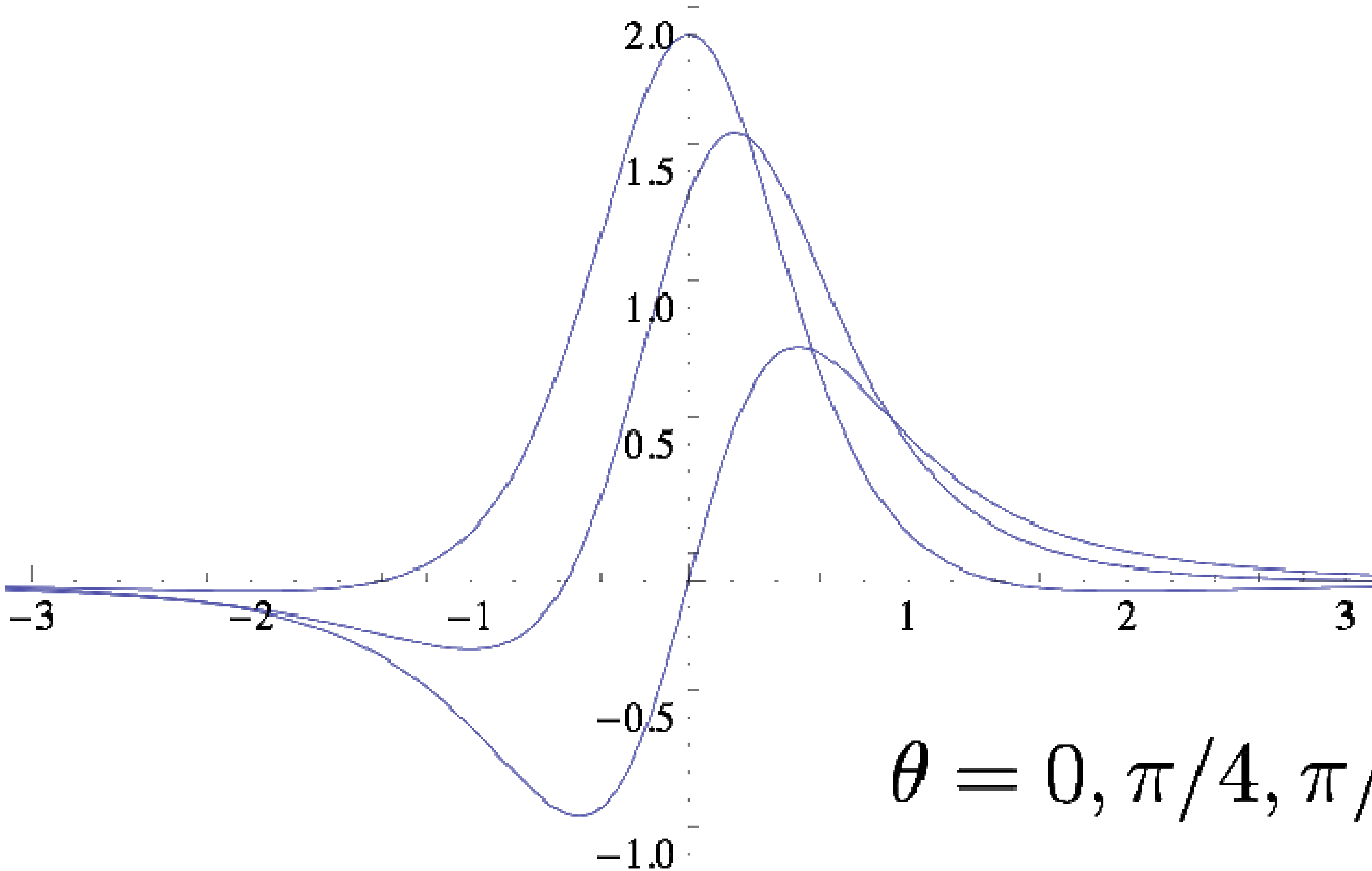


plicity, restrict to two dimensions, with $\mathbf{m} = (\cos\theta, \sin\theta)$. ion $(x, -d)$ leads to a signal

$$s(x) = \frac{q}{(x^2 + d^2)^{3/2}} \left\{ \frac{3d(-x\cos\theta + d\sin\theta)}{x^2 + d^2} - \sin\theta \right\}$$

urface $y = 0$.

$$s(x) = \frac{q}{(x^2+d^2)^{3/2}} \left\{ \frac{3d(-x\cos\theta + d\sin\theta)}{x^2+d^2} - \sin\theta \right. .$$



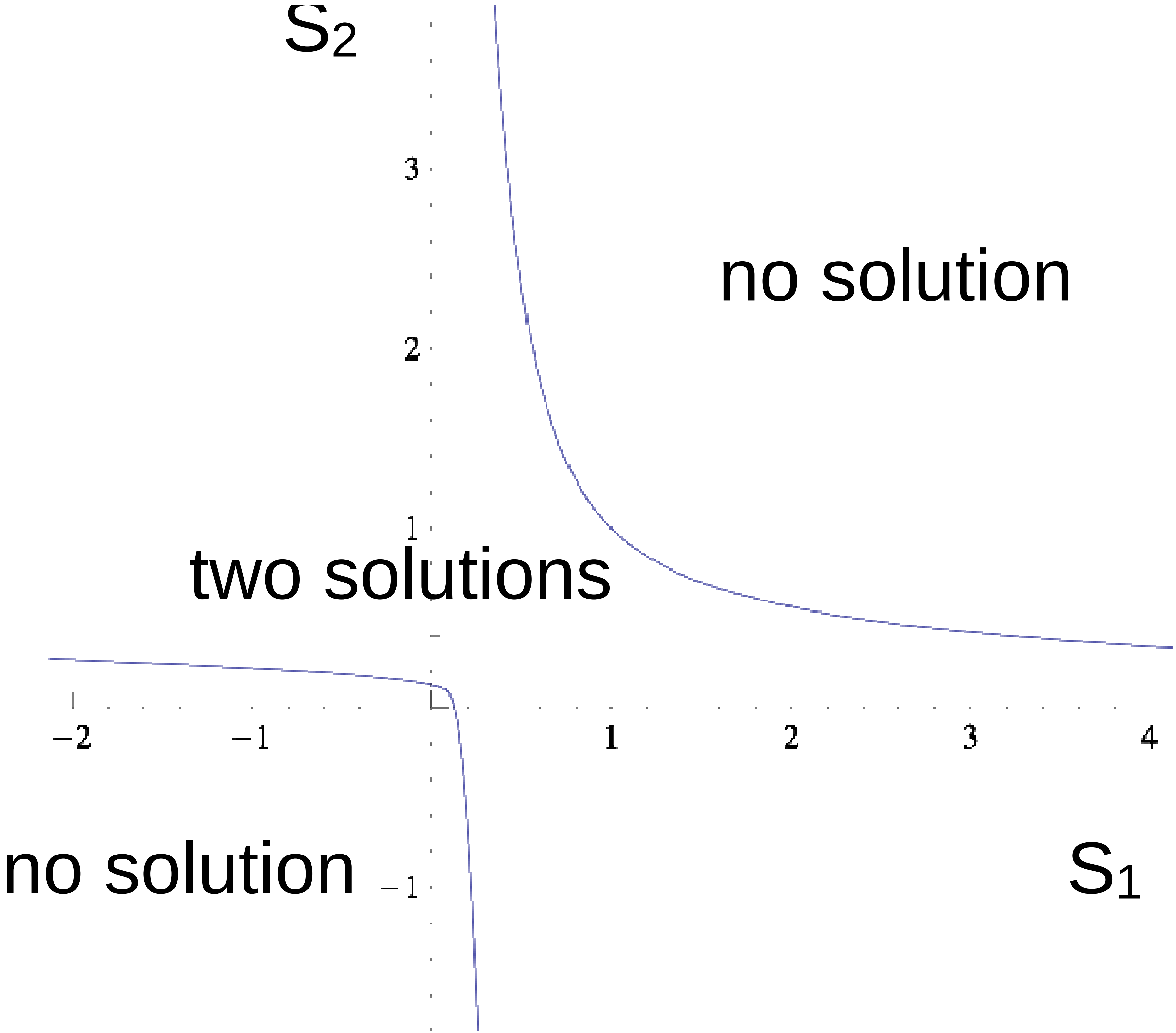
$\theta = 0, \pi/4, \pi/2$

ose we measure the signals at three sensors; say $s(x) = 1$ (with
;enerality), $s(x-1) = s_1$, $s(x+1) = s_2$. We pose the question:
easured values consistent with a single dipole? If not, we must
ig at least two sources.

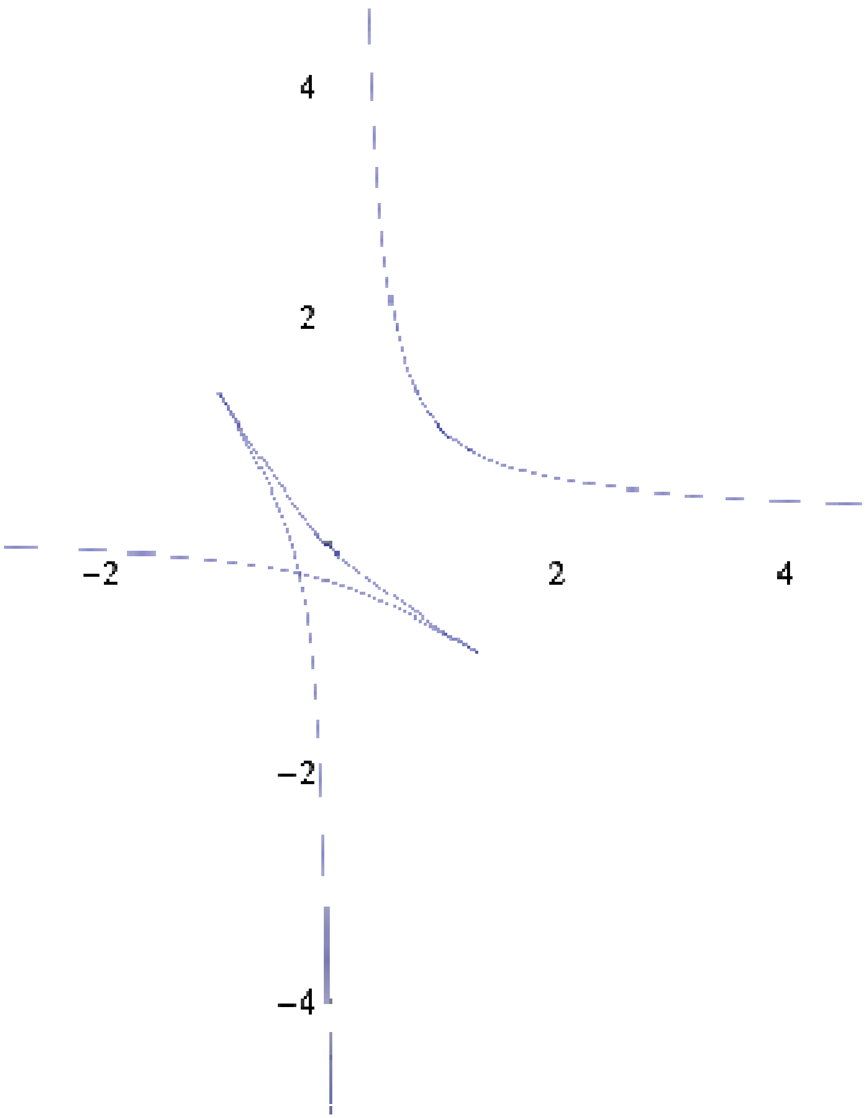
liminating q and θ, we get the equation

$$\frac{{}^2 + (x-1)^2)^{5/2}\,(2d^2 + x + x^2)}{2\,(d^2+x^2)^{5/2}\,(2d^2+x^2-1)}\Bigg\} s_1 + \Bigg\{ \frac{(d^2+(x+1)^2)^{5/2}\,(2d^2 - x}{2\,(d^2+x^2)^{5/2}\,(2d^2+x^2 -}$$

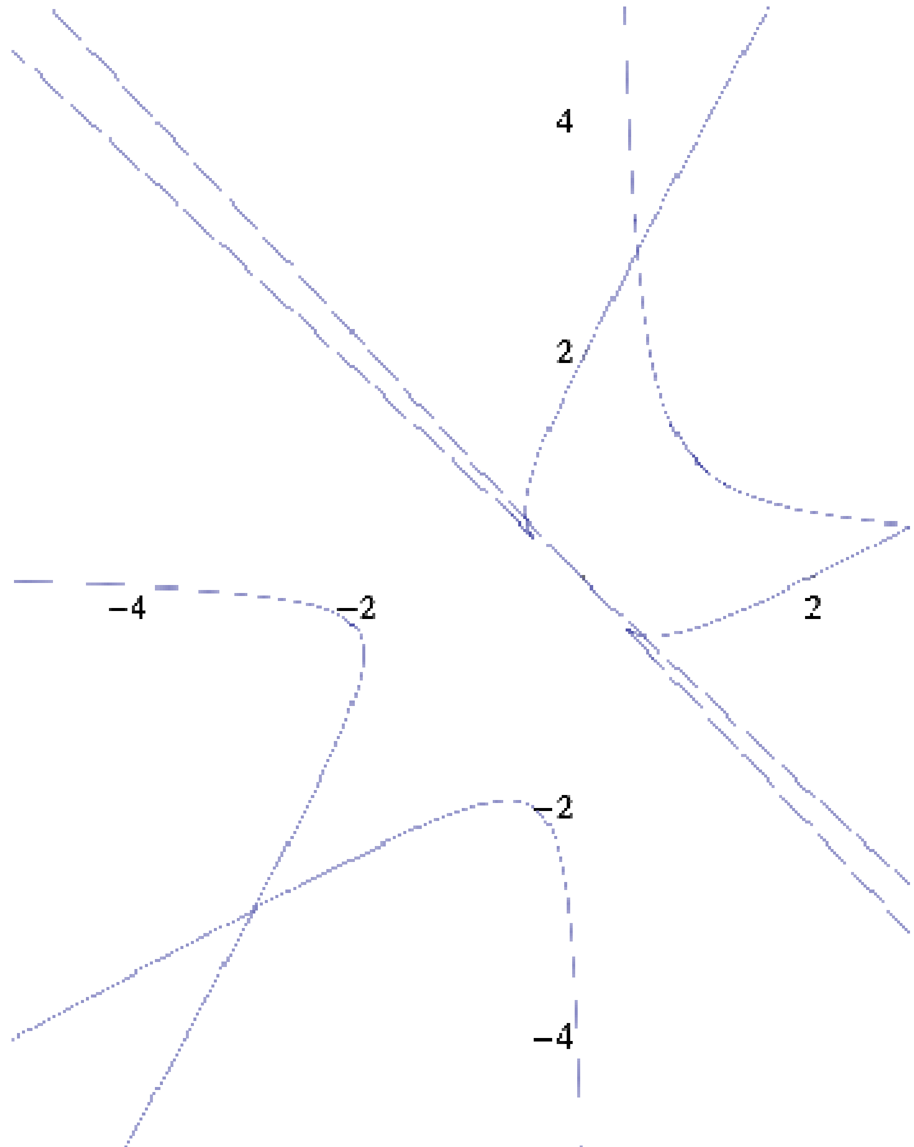
moment, suppose we know $d = 1$ (this is quite realistic in practi
is equation can have two or no roots for x, depending on the val
d s_2.



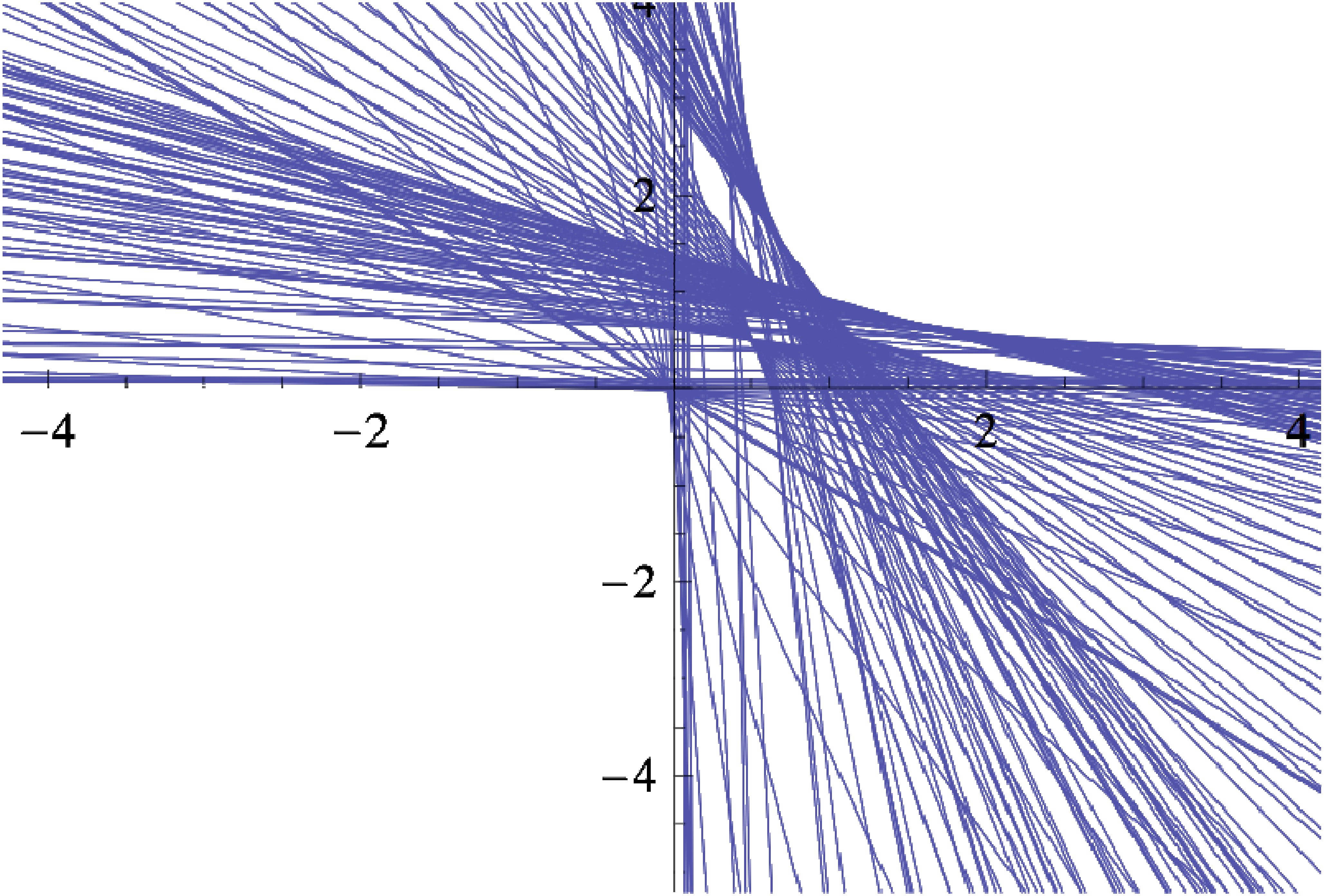
S2
3
2
1
no solution
two solutions
−2
−1
1
2
3
4
no solution
−1
S1



$d = 0.375$



$d = 0.35$



d exceeds a critical value ≈ 0.345

Questions?